GRASSLAND DEVELOPMENTS IN THE UNITED KINGDOM IN THE LAST TWENTY-FIVE YEARS[1]

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THE past twenty-five years have seen important developments in grassland and these have played a prominent part in building a more intensive agriculture. The plant breeder has evolved new strains of herbage plants which have entered commerce, their authenticity being ensured by certification schemes latterly on a comprehensive national scale. There has been emphasis on the long ley as a crop in rotation, particularly in the mixed-farming areas. More fertilizer is used on grassland than before and more attention paid to grazing management and grass conservation.

Many of these developments, based on experimental work carried out since 1920, were profoundly influenced by the work of Stapledon at Aberystwyth [1]. During the period between the two world wars, British grassland was largely based on permanent pastures and meadows [2], of which several million acres were ploughed for wartime cereal production and have been added to the area under rotation farming. The pivotal role of the ley within the farm systems of this country has been accepted in farming practice, but the amount of field experimental work carried out on the ley, although impressive, still leaves an embarrassing number of problems that await solution. For example, no wholly satisfactory method has been evolved as yet to evaluate different grasses and other herbage plants in terms of animal product. Closely associated with these problems is the design and conduct of field experiments [3, 4] involving the grazing animal, and in this connexion there is an array of unsolved problems.

Seeds Mixtures

Agronomic studies to compare different seeds mixtures have been in progress for a long time [5, 6, 7, 8, 9, 10, 11], and these have been intensified in recent times. The advent of new plant material, including products of the breeders, demanded that a complete study of seeds mixtures should be made, and the result has been that prescriptions are much simplified and seed rates considerably reduced. The following table (p. 196) serves to indicate these trends and shows the use made of the bred strains in modification of the seeds mixture.

This type of mixture now includes fewer species and a reduced total seed rate; the principle of mixing strains is applied to extend the grazing season and to lengthen the potential life of the ley. Still simpler mixtures using one grass and one clover are employed; the mixture of

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ryegrass with white clover provides an example, again with a mixture of strains. There is a variety of seeds mixtures for the long ley and these are usually based on five or six species with seed rates of between 20 and 30 lb. per acre. The precise details of any seeds mixture still allow for controversy, and there is little in the experimental evidence to indicate

Before 1930		*1950 onwards*	
	lb. per acre		*lb. per acre*
Italian ryegrass . .	5	Italian ryegrass (S.22) .	2
Perennial ryegrass . .	16	Perennial ryegrass (S.24)	6
Cocksfoot . . .	8	,, ,, (S.23)	4
Timothy . . .	4	Cocksfoot Danish .	2
Rough-stalked meadow grass . . .	1	,, (S.37) .	4
Red clover . . .	4	Red clover (early) .	1
Alsike clover . . .	1	,, (late) . .	2
White clover . . .	1	White clover (S.100) .	1
Trefoil . . .	1	,, (S.184) .	1
	41		23

that minor differences are in fact translated into higher yields. Yield ultimately depends so much on the level of fertilizer treatment and on the management applied to the ley. Clearly the latter should carry an adequate balance of grass/legume; it should also be flexible as regards its management and show the ability to regain high production even after a period of mismanagement. The seeds mixture, however, does provide the basis for sustained production throughout the life of the ley, and so makes it possible to offer grazing over an extended season within the calendar year. Once the ley is established, its botanical composition, management, and manurial treatment largely determine its yield and its persistency.

Seeds mixtures can, therefore, be designed to provide herbage at different times of the year, to extend the effective grazing season and so to fill the gaps caused by dry weather in summer. Interactions between type of herbage, its management, and manurial treatment are not easy to dissociate, but experimental work has re-emphasized the importance of the legume component in grassland. Clover not only enriches the soil, but it adds to the total yield of herbage and to the nutrition of the associated grass. The residual value of the clover root has long been accepted, but its 'current' value as a nitrogen collector can now be measured [12, 13]. Under British conditions the annual nitrogen value of a clovery sward is of the order of 150 lb. N per acre, but in New Zealand, Sears [13] finds the figure to be considerably higher than this.

Ley Establishment

Successful establishment of any crop is an obvious first necessity, and much has been done in connexion with this problem on leys. Timely cultivations, a fine top tilth with good consolidation making for a firm

seed-bed, are an essential prerequisite for a good take of seeds. Important also is the treatment applied to the new sowing, including fertilizer application to the seed-bed and grazing during the period of early establishment. Sowing by drill as opposed to broadcasting has some advantage in that the seeds can be sown at a uniform depth [14]. Better takes follow sowings made under the grazing nurse-crop and in conditions where the grazing animal has access to the new ley within some 6 or 8 weeks after sowing. The composition of the seeds mixture influences the establishment of its individual components. Ryegrass grows very rapidly from seed and if sown at heavy seed rates can be exceedingly aggressive, with the result that other species are suppressed. Meadow fescue and timothy are particularly sensitive to competition at this stage, and because of this, mixtures based on these two grasses, but from which ryegrass is omitted, are now in common use and represent a distinct departure from traditional mixtures.

The worst features of inter-species competition can be minimized by careful grazing control during the establishment period. Leys are difficult to establish under heavy corn crops and it is preferred not to sow under corn or other crop known to be competitive. To ensure good establishment, it is best to sow without a cover crop, or else to use one that can be grazed soon after sowing. Italian ryegrass, rape, and cereals (used for grazing) have all been tried, but none of these is completely satisfactory. Westerwold (or Express) ryegrass makes quick growth without being unduly competitive towards the basic constituents of the mixture and may well prove satisfactory as a grazing-nurse.

Management

Marked modifications in management practices have taken place during recent years [14], but the 'under-use' of grass is still a feature of the British countryside, particularly in summer and early autumn. This results in considerable losses in production. Where leys are managed intensively, yields in excess of 30 cwt. per acre calculated as U.S.E.[1] are commonly achieved from grass alone, and this compares with the national average of between 10 and 15 cwt. U.S.E. per acre. Grassland responds well to fertilizer treatment, and it also responds to good management. To make the most of grass in terms of quantity and quality, it is best to graze-off quickly and to rest after each grazing period in order to allow the plant to recover its vigour. Interesting practical problems arise in this connexion, particularly at periods of flush growth and again at times of scarcity, for the tendency at flush growth is to under-graze, and at times of scarcity to over-graze, both practices being detrimental to ultimate yield.

The classic experiments of Martin Jones [16] first concentrated attention upon the influence of different grazing régimes on the yield and botanical composition of a mixed sward. Different methods of defoliation also influenced the nutritive value of the herbage, particularly where this depended on the proportion of clover. Recent trends in pasture management include the use of the gang mower to keep the sward in a

[1] Utilized starch equivalent.

dense leafy state, to encourage the spread of leafy types and to alter the species complex by elimination of undesirables. So-called 'zero' grazing whereby grass is cut and fed elsewhere is receiving renewed attention, particularly with respect to its mechanization. Zero grazing is, of course, traditional in many parts of Europe; in that case labour input is high, but if mechanized the system does offer opportunity for better use of pasture, provided the excretal equivalents are returned to the sward, for this must be done if production is to be maintained.

The widespread use of lime since 1940 has proved most beneficial, particularly where the standards of grassland management have also been adjusted. Grazing management at its best is comparatively efficient, but on the average farm it is not at its best and, speaking generally, too little fertilizer is used on our grasslands. Silage making has had an important influence in improving pasture management, but the quantity of silage made is still much below requirements and progress is slow, although there is general agreement that more grass should be ensiled. The high value of phosphates and potash and particularly their good influence on white clover has been recognized, but the secondary effects on soil nitrogen and on the nutrition of the grass have been less widely appreciated. The indirect effects of mineral fertilizer exceed their direct effects as a result of clover stimulation and of the consequent increase in soil nitrogen to which the grass responds.

The major obstacle to full pasture utilization is the uneven rate of growth in pasture, not only within the season, but in successive seasons. The more intensive use of grass and proper methods of conservation, together with irrigation as a tool, all help to create better conditions for the even growth of grass, whilst the use of special-purpose leys, including the lucerne ley, help enormously to produce herbage at predetermined times whether for cutting or for grazing. There is no simple solution to this problem, but the use of advanced techniques does extend the grazing season and fills some of the gaps. The aim must always be to make available high-quality herbage at all times of the year, and this can be done to a large extent by the combination of grazing and conservation designed to satisfy the needs of the ruminant at normal production. When it comes to animals at high production, including dairy cows, the total daily intake of dry matter probably sets the upper limit to production from pasture alone, so that supplementary feeds of high energy value and low fibre content become necessary.

Seed Production

A large volume of experimental work has been done in the production of seed crops, particularly with grasses, and the new techniques have been put into practice very successfully in the grasses, but with less success in clover. Herbage seed crops require high fertility, the grass being responsive to N whilst legumes demand an adequate basis of PK, assuming in both cases that the lime status is satisfactory. Clover-seed yields are erratic and depend very much on weather conditions at pollination and harvest, although modern machinery has greatly simplified the harvesting problems. Seed yields in the grasses have greatly increased,

especially in cocksfoot where growing for seed in widely spaced drills and with heavy fertilizer dressings has made it possible to grow crops of the shy seeders, including leafy strains, of upwards of 10 cwt. of clean seed per acre, although the average yield is considerably lower than this. A new grass/clover seed industry has developed around the bred strains, and a large part of the herbage seeds used in Britain is now home grown, whilst there are the beginnings of an export trade to America and elsewhere.

Strain in Herbage Plants

A large number of new strains has become available in commercial quantities during recent years. Most of these strains are the result of breeding and selection and, in the main, represent leafy types. As a consequence, the British farmer has a much wider choice of plant material for his seeds mixtures than he had before the last war. As pasture components the leafy strains are easier to control, and they provide a more nutritious crop not only as pasture, but also for conservation. They help to extend the grazing season during both summer drought and the cold weather of late autumn and early winter, some strains being particularly winter green. Yield tests have not shown striking differences over the year as between different strains, but this fact must not be given too much stress, because particularized strains may out-yield all others at certain times of the year, and this characteristic is obviously a most valuable one.

Herbicidal Treatment of Grassland

The use of weed killers has spread enormously in arable crops, but their use on grassland has been much more restricted. However, renewed interest has been aroused, since some of the hormone herbicides are now known to control rushes, buttercups, and to some extent docks, all of which are important grassland weeds. The most widely used compounds for these purposes have been MPCA and 2,4-D, but both are harmful to clover, whilst butyrics, MCPB and 2,4-DB, which are much less harmful to clovers, are not on the whole quite as effective over the whole range of weed species. Recently, dalapon, aminotriazol, and others have been used experimentally for the control of grass in leguminous swards. These new herbicides offer the means for destroying existing turf without ploughing and for the establishment of leys on surfaces so pretreated. These experiments may, therefore, lead to advances in the whole concept of land reclamation under conditions where the established methods do not fully apply. Some of the new herbicides also make possible the better control of weeds in the new leys. Dinoseb, for example, will control chickweed and other annuals in the direct-reseeded ley.

Permanent Grasslands

Permanent grass is less productive than leys, although when it is treated intensively and when soil fertility is high the general attributes of the ley can be maintained for a long time. There is in fact no fundamental difference between intensively treated old pasture and similarly treated leys, since the basic unit in the grass is the tiller which itself is

short-lived and can originate and die at any time of the year; thus the population in the grassland sward is not static, but ever-changing in both the number and vigour of its unit tillers. This fact gives the grazier adequate opportunity to control the composition and nutritive value of his pasture lands, and he can do this by changes in management or manurial practice, because both of these materially influence the growth and production of tillers.

The war produced many changes in the pattern of cropping, and there is now a greater awareness of and interest in the results obtained from field experiments. The following statement shows some of the changes that have occurred in the acreage under various crop groups between 1939 and 1957 in the United Kingdom [17].

	United Kingdom—'000 acres	
	1939	*1957*
Permanent grassland . . .	18,773	13,487
Leys incl. lucerne leys. . .	4,125	6,348
Crops and fallow . . .	8,781	11,176
Rough grazings	16,539	16,782

There has been a decrease in the acreage under permanent grass and an increase in leys, with the net result of a major reduction in the grassland acreage (its corollary, of course, is a larger acreage of tillage crops) on which an increased number of cattle is maintained [17]. Sheep numbers, which were reduced sharply during the war years, are now increasing and will soon attain pre-war levels. There has been an all-round intensification of grassland farming with much greater use made of new knowledge gained after experimentation. Yields have improved on the leys as a result of better seeds mixtures and more balanced manuring. Further increases are clearly possible and will take place as more farmers make use of existing knowledge. Trades ancillary to agriculture, together with marketing organizations, have played an influential part in those developments that have already taken shape. Something of an agricultural revolution has occurred and indeed is still proceeding. This has been made possible as a consequence of the scientific and technical information now at the disposal of the farming community. The trigger action came during the war when our fortress economy resulted in more emphasis on agriculture, and this tendency has been continued into the post-war years. These conditions demanded maximum output from the land, but now there is a gradual transference of emphasis to maximum output per labour unit with a lowering of costs.There is here, however, no real incompatability, although new problems are being raised which are a challenge to the industry as a whole, farmer, trader, and scientist alike, for all are deeply concerned with their solution.

Hill Lands

Although widespread efforts have been made to improve the hill and moorland grazings of this country, there has been no substantial change

in the general pattern, which remains much the same as it has been for generations [18]. However, the increased interest in hill reclamation has prompted the ploughing up of many areas which have been successfully reseeded with, it is believed, considerable benefit to the properties as a whole. Much of this work has been experimental and the developments largely exploratory. Ploughing and cultivation costs are often high, although grants-in-aid have reduced such costs to economic proportions. Some of the reclaimed areas have not been so successful; a small proportion has even reverted, particularly where rushes and other moorland plants have invaded the new sowings during the early life of the ley. The problem of hill reclamation and of hill farming needs constant re-examination. There is an aggregate of nearly 17 million acres involved, and this plays an important part in our agricultural economy, producing perhaps a third of the wool clip, and there is an annual export of between 2–3 million sheep from the hills to the lowlands. At the present time the hills of Britain provide fairly adequate grazing for sheep and cattle during the short summer, but the winter is long and keep is scarce at that time. Shortage of winter forage therefore is the key problem, and the present position can be improved only after new herbages have been introduced and maintained. It is well known that white clover and the better grasses thrive on the hills under conditions where soil fertility is adequate and grazing management is properly adjusted.

Ploughing and cultivation are frequently difficult, but reseeding has proved most successful where it has been possible to treat the new sowings much in the manner of lowland pastures. There have also been successful attempts to change the composition of the moorland swards without cultivation by surface seeding and the application of lime and phosphates. A recent development is the use of the sod seeder, a special drill which sows in existing turf. It may be that this sort of development can be linked with certain herbicidal treatments designed to give a complete or partial kill of the natural vegetation. Now that we have herbicidal mixtures that are capable of killing grasses as well as weeds, we should give more thought to this method of seed-bed preparation which is promising and needs further examination.

Ley Farming

The concept of ley farming differs in degree from that of alternate husbandry because of the particular emphasis laid on the ley as a crop in the rotation, and on its pivotal nature in relation to feeding animals, and to upkeep of soil fertility. As a result of frequent cultivation and cropping there is usually a reduction in organic matter in arable soils, and a loss of soil structure as a consequence. The period under the grass/legume ley is recuperative: soil structure improves and root matter accumulates. In addition, the value of the herbage as feed for animals is very important, as is also the return of dung and urine, the nutrients of which go back into circulation. The output of U.S.E. on well-managed leys is comparable to that from cereal and other crops, while leys generally are more productive in terms of crude protein, and this places grassland high in the scale among fodder crops, even though the

converse is frequently stated when comparisons are made between grass and arable crops. Grassland, however, must always occupy an important place in British agriculture, because of its value in the rotation, as well as the basic role it plays in the provision of food for the meat and milk animal.

The production and use of grass is quite complex and its proper exploitation often demands an appreciation of the underlying principles of plant growth and an understanding of the effects the grazing animal has upon the pasture. For satisfactory growth it is necessary to have an adequate supply of nutrients in the soil, and this in practice means the intensified use of fertilizers. Commercial quantities of these have been greatly increased since the beginning of the century, but even now nutrient deficiency is frequently a serious limitation to production on a large part of the grassland acreage, particularly on permanent pastures. The use of Ca, P, and K in adequate quantities is vital because of the benefit which accrues to white clover and other legumes, and this has important secondary effects upon the status of soil nitrogen. The value of white clover is axiomatic and there is no doubt about the usefulness of nitrogen, but it is unfortunate that fertilizer nitrogen tends to depress the growth of clover. This is a subject in which there is need for further fundamental research which should be supported by carefully controlled husbandry experiments of a more practical nature. The problem is to use the grass/clover sward to the best advantage, to associate with it the use of nitrogen, and to decide the point at which maximum yields are obtained and also the best monetary returns.

Exciting things have been happening to British agriculture during the past two decades. Before 1940 the industry had passed through a long period of depression, and there was little incentive to bring about serious changes in the farming enterprise, and certainly none that would demand extra capital. The input of fertilizers on grassland was often at very low levels and it was exceptional to find grassland being farmed intensively. Soils almost everywhere were acid and also gave marked responses to phosphates. The importance of potash was beginning to impress itself upon the industry and the same was true of nitrogen, but the aggregate amounts of these fertilizers used on grassland were quite small. In this country we now use upwards of 250,000 tons N per annum, of which probably about a third is applied to grassland. If all our grassland was intensively treated with fertilizers, however, we might well use up to 200,000 tons N annually on grassland alone. After all, this would only allow an average of some 30/35 lb. N per acre on 6 million acres of leys, and 20/25 lb. per acre on say 10 million acres of permanent grass.

In 1955 about 370,000 tons P_2O_5 and 275,000 tons K_2O were consumed in the United Kingdom. These figures represent respectively twice and four times the consumption figures for 1939. Only a portion of these quantities was of course applied to grassland, and if our grasslands were to be manured at optimum levels, considerable additional quantities of these fertilizers would be needed, possibly adding as much as 50 per cent. to the 1955 totals. Approximately $2\frac{1}{2}$ million acres of agricultural land are limed annually, which suggests a liming rotation of

once in 8 to 10 years. About a quarter of the permanent grass receives phosphate in a given year, while it is possible that the majority of leys receive P_2O_5 in most years; probably no more than a third of the grassland receives nitrogen fertilizer and a sixth potash in any one year. If the standard of manuring of grass was comparable with that found on intensively managed farms where N, P, and K are applied annually, then the overall production from the grasslands of this country would increase enormously.

Pasture Yield and Animal Intake

Apart from the work of Somerville [9], there is little in the earlier literature to show comparisons between levels of pasture output as measured through the grazing animal. Stapledon and Jones [19] working with sheep, showed that there were differences related to sward management and density of stocking that were reflected in live-weight gains. Recently there has been more emphasis on measuring output of grassland through the animal, although our techniques are still not accurate enough and better ones have to be evolved [20]. Clearly there can be no one all-inclusive figure to represent pasture yield in terms of animal product, simply because yield is not absolute either for pasture or for animal. This presents us with a real problem, the solution of which still requires a number of diverse approaches designed to define yield and quality of herbage as they affect the nutrition of different classes of animals.

The content of crude protein has been a useful though a rough yardstick of quality in herbages. Woodman *et al.* [21] showed that young leafage was high in crude protein, low in fibre, and fairly high in minerals, and that as the leafage became older the proportion of protein decreased and the fibre increased. Fagan and Jones [22] found that leaf lamina was richer in nutrients than stem and leaf sheaths in the grasses. These findings suggested to the plant breeder that he should select for leaf production, and on the whole where this has been done, it has proved sound procedure. Current work [15], however, suggests that there is no exact relationship between nitrogen or crude protein content and the digestibility of herbage, although there always seems to be a general trend for highly digestible herbage to be rich in protein.

The quantity of herbage eaten by the grazing animal is difficult to assess accurately when it is still at pasture [15]. Partly for this reason the nutritive value of herbages has not yet been adequately determined. Digestibility determinations and estimations of intake, when conducted on cut materials fed indoors, do not simulate grazing in the field, for the pattern of behaviour is quite different in the two circumstances. High moisture content and immaturity are not always favourable features of the type of herbage most useful to the grazing animal, and indeed such immature herbage may well be responsible for some of the metabolic ailments associated with grazing. During recent years techniques have been developed to assess the quality and quantity of herbage eaten by the animal. Assessments of consumption by taking pre- and post-grazing samples are open to criticism. The newer faecal index methods,

together with the use of tracers and digestibility trials, may well provide the right techniques and offer in many cases important advances on previous thought. We know that intensity of stocking influences the amount an animal will eat; also quality of the material itself, rate of growth, and accessibility are all factors concerned with palatability and therefore with pasture intake.

Management in Relation to Parasitism

A degree of control of endo-parasites is possible by means of grazing management where this is designed to reduce the intake of infective larvae. The numbers ingested can be influenced by the intensity and frequency of grazing. Grazing on a long rotation alternated with cutting for conservation, and using different classes of stock on consecutive grazings, both tend to reduce although not to eliminate parasitism. The concept of providing parasite-free pasture on which parasite-free animals are carried is under investigation and offers a new approach to the whole parasite problem. The benefits of mixed grazing with cattle and sheep have long been recognized. Recent studies with sheep confirm the value of rotational grazing and indicate that pastures should be managed with increasing attention to detail as the rate of stocking is increased and the system of sheep farming becomes more intensive [14, 23]. It would appear that two years free from ruminant stock is needed to ensure that the land is free from alimentary parasites of all types. The value of ley systems for providing worm-free land is axiomatic. It would be of great interest to follow the progress of a breeding flock of sheep managed in a worm-free condition on worm-free pasture.

There are a number of metabolic disturbances which cause serious losses in production, and in extreme cases death. Bloat and grass tetany are examples of these diseases; both of them seem to be related in some way to the amount and quality of pasture eaten by the animal. The condition is usually associated with young, immature leafage. The prevention of these diseases is clearly important, but no adequate control methods have as yet been devised. Indeed as pasture production increases, there is an ever-growing tendency for the incidence of these disorders also to increase. Grass tetany (hypomagnesaemia) is a physiological disfunction [24] which seems to be correlated with high K and P content in the herbage, and to low Na, Ca, and Mg [25]. By carefully controlled grazing and good herd management losses due to these disfunctions in cattle are minimized, but the causes are not well understood, and this makes remedial measures somewhat empirical. Surveys made with both bloat and grass tetany in Britain have indicated their widespread incidence with often quite a high death-rate. Both disorders occur most frequently on leys in early spring, but acute conditions may occur at any time and on any type of pasture including permanent grass. Trace element deficiency and/or excess does not usually reflect itself in diagnostic symptoms in the grasses, but may do so in the legumes. Some deficiencies, e.g. cobalt and copper, may be associated with ill health in the animal yet cause no pronounced symptoms in the herbage [26, 27].

Conservation

Important advances have taken place in the techniques of grass conservation.

Hay. Traditional haymaking methods have been re-examined and new ideas introduced, including baling in the field, curing on tripods, and the frequent stirring or tedding of newly cut hay in order to reduce the time needed for sun curing. Barn drying is still in the experimental stage but shows much promise. By this system hay is partially cured in the field, the process being done as quickly as possible, and finally dried under cover. Haymaking by traditional methods becomes more difficult as the crops become heavier and consist of more leafy material. Also the tendency to cut for hay earlier in the spring accentuates this problem. Improved techniques are, therefore, an urgent necessity. Frequent tedding, lacerating the crop as cut, the use of racks or tripods, baling, and barn drying are all valuable adjuncts to traditional haymaking, and offer a means for producing good quality hay with less regard to weather conditions than hitherto.

Silage. Silage provides an excellent means for conserving grass and has also the advantage that silage making fits in well with intensive management of grassland. At the period of flush growth it is essential that the surplus be removed from the field while still in the leafy stage. Silage cropping satisfies this requirement. Recent advances in silage-making techniques are due appreciably to research and experimental work initiated by Watson [28] and others from 1930 onwards. Various types of silos have been developed—stacks, clamps, tower and trench silos, most of the grass being ensiled without chopping, but many of the modern forage harvesters either lacerate or chop the crop. A recent development is the self-feeding of silage from stack or clamp which is built on concrete and under a roof. Changes in methods of handling the crop, both at harvest and when feeding, have been accompanied by investigations into the use of additives, including acids, molasses, and more recently sodium metabisulphite, designed to preserve the silage. Studies of the qualities and nutritive value of silage suggest that silage high in protein and dry matter and low in fibre provides a feed comparable in value with summer pasturage.

Dried grass. Dried or dehydrated grass has been made in considerable quantities during the past couple of decades and it proved very valuable as a feedingstuff during and immediately after the war. Drying is undoubtedly an ideal method of conservation so far as it provides a product of high quality, but the cost of drying appears to be excessive if the material is to be used as such for cattle food. The bulk of dried grass now made in this country is used in preparing compound feeding stuffs.

Other conservation methods. The deep freezing of grass is employed as an experimental tool and provides a first-class method of preservation. Frozen grass is palatable and apparently undergoes no nutrient change in the freezer. As in the case of dried grass, costs are high and frozen grass does not lend itself to easy transport. If, however, refrigeration and power costs are greatly reduced, the product would have

much to commend it. Another exciting possibility is the irradiation of fresh grass by gamma rays. This seems to be an excellent way of preserving young grass. Small quantities have been irradiated for experimental purposes at the Grassland Research Institute and this has been fed to a sheep without ill effect. This is a completely new concept, but clearly the technique would have to be worked out and the cost of treatment examined. It provides a new approach to the problem of conservation which may well prove important.

Leaf Protein Concentrates

It had been suggested before the war [29] that high-quality protein could be extracted from leaves and the product used for preparing protein-rich diets for human feeding, but the process was never developed commercially. Subsequently Pirie [30] has made a study of processing leafy material in preparation for large-scale extraction of a protein concentrate. Raymond and Tilley [31] suggest that extraction methods are too costly at the present time, making a protein concentrate expensive compared with seed proteins of equivalent or superior biochemical value. There is need for a great deal of careful research into these problems and particularly as regards the leaf proteins extracted as concentrates and fed in controlled feeding tests to various types of animals. The few rather crude tests that have been made suggest that leaf protein concentrates obtained by normal extraction processes are deficient in certain ingredients, possibly amino acids, and that the product is not a wholly satisfactory source of protein for poultry and pigs; when fed to these animals it appears to be of rather poor biochemical value compared with high-quality animal protein. However, the underlying concept of leaf-protein extraction seems a most attractive one, especially when it is recognized that green leaves are a major terrestrial source of protein, and if this could be fed direct to humans, it could reduce enormously the very large quantities of energy now used in maintaining animals to produce meat and other products for human consumption.

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APPLIED SCIENCE IN BRITISH WEST INDIAN AGRICULTURAL DEVELOPMENT 1933–58: AN EVALUATION OF PROGRESS[1]

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A REVIEW of progress in the application of science to agriculture in the British West Indies during the past quarter-century sets the reviewer a nice problem in selection, not only because the pattern of agricultural activities varies so much from one island to another, nor even because the tempo of change has differed so much from place to place, but because some of the most spectacular and widely recognized advances have occurred in the secondary aspects of agriculture, whereas some of the most truly significant advances which have occurred in its primary aspects have not yet become outstanding.

In raising the level of total profit from agricultural sources even a trivial advance in a large industry might be more effective than a substantial advance in a minor one, yet if allowance is to be made for this by judging the magnitude of each advance in relation to the state of the industry in which it has taken place, our conception of what ranks as outstanding may become too academic: we cannot altogether ignore the importance of the industry concerned in the general economy of the region. If we change our approach and ask ourselves what innovations in agriculture would most impress a West Indian returning home today after an absence of twenty-five years, we should soon realize how many changes have occurred which, even when recognizable as advances, are not (or not yet) to be rated as outstanding. In at least one Colony, for instance, the practice has spread of burning sugar-cane fields prior to reaping: this is perhaps to be classed as a compensatory development and not as an advance. The substitution, on field-carts, of automobile wheels with pneumatic tyres in place of the large iron-shod wheels is extending, but must often be contributing more to easing a physical burden than to increasing a profit. Use of the aeroplane in the management of sugar estates, though perhaps supreme among local examples of enterprise, is still so uncommon as to be negligible in an assessment of regional developments.

Inequality between islands in the number and extent of agricultural changes is to be expected, but not inequality in elementary appreciation of the value of soil fertility, and we might contrast, with legitimate surprise, the advent and current vigour of soil-conservation measures in a few areas with their absence from others topographically similar. Again, there are striking inequalities in levels of production between different crops today and twenty-five years ago: the great expansion of a grapefruit and orange industry, contrasted with a general shrinkage in the

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production of limes; the revitalization of the sugar-industry, contrasted with a great fall in cocoa production. Botanical and zoological developments have almost invariably taken place under the aegis of Government, whereas private enterprise has usually led the way in sponsoring chemical or mechanical innovations.

In considering the materials and methods which have been brought into use over the widest area, and which have proved of benefit to estate-owner and smallholder alike, we note the organization of marketing and the expansion of local processing of agricultural products; the adoption of superior planting material of sugar-cane, cacao, citrus, rice, and, here and there, of better cover-crops and pasture grass, and correspondingly, in the livestock industry, of superior breeding stock. We note, too, the extending and diversifying use of mechanical equipment (usually power-driven); the increased use of chemical fertilizers, and the introduction of new techniques in control of pests and diseases.

The first of these advances, the formation of promotional and protective Associations, which took place chiefly during the years of depressed markets,[1] has been an important precursor to the substantial extension of processing, notably of coconut products, grapefruit and oranges, and, in Jamaica, of milk, but it is an advance which can scarcely be attributed to the application of agricultural science. Advances in the second class, however—the provision of better planting material—undoubtedly represent such a practical application.

Improved planting material. A source of new varieties of *sugar-cane* was created by the establishment, in 1932, of a central sugar-cane breeding station in Barbados, supported by governments of sugar-producing West Indian colonies. The breeding programme has proved highly successful, and a very large proportion of the sugar-cane varieties now planted in the British West Indies originate from that station.

In the *cocoa* industry only potentially high-yielding trees are planted today. These have been derived, in the first place, from selections made by the late Dr. F. J. Pound while a member of the Cocoa Research staff of the Imperial College of Tropical Agriculture, after a careful study of the relevant characteristics of the local cacao-tree population; more recently a further valuable source of material has become available in the Witches'-broom-resistant progeny derived from crosses with resistant trees introduced by Dr. Pound from South America.

In *citrus* cultivation the early problem was not to isolate high-bearing varieties, but, for the purpose of enhancing resistance to disease, suitable stocks on which to grow them. For their efforts in pioneering the investigation of this problem high praise must be accorded to the Department of Agriculture of Dominica, and to leading members of the small coterie

[1] The following include only the better-known examples: the Jamaica Coconut Growers Association (1930); the Coconut Growers Association, Ltd. (of Trinidad) (1936); the Co-operative Citrus Growers Association of Trinidad and Tobago, Ltd. (1932); the West Indian Lime Oil Sales Co., Ltd. (1935); the West Indian Limes Association (1938); the West Indian Sea Island Cotton Association (1933); the Jamaica Banana Producers Association, Ltd. (1927); the Cocoa Planters Association of Trinidad, Ltd. (1925); the Sugar Manufacturers Association of Trinidad (1921) (Inc.) (1942); the Sugar Manufacturers Association of Jamaica (1929).

of citrus growers in that island. Although their main citrus export, limes and lime products, dropped from some 422,000 to 300,000 barrels in four years, following the appearance of Withertip disease in 1922, their task began only after 1928, when, in consequence of 'dieback' and hurricanes, the decline rapidly accelerated, until by 1935 exports had fallen to 28,000 barrels. The botanical work involved assessing all available citrus species and varieties as possible stocks on the main soil types, yet, in spite of discouraging market conditions, which limited the cash available for such exploration, the chief problem was solved by the middle 1930's. Elsewhere the investigation of citrus root-stocks was generally taken up after 1930, with the inception of the grapefruit industry, and has almost invariably been conducted by local Departments of Agriculture. These Departments must also be credited with introducing and making available superior strains of *rice* and of *pasture grass* (and, in stockbreeding, for determining the best types of cross and for introducing better sires).

The position is rather different in the West Indian *Sea-Island Cotton* industry, where the emphasis has lain not on developing superior material for planting but on preserving the existing strains from contamination. This task has been the responsibility both of the Departments of Agriculture in the islands concerned and of the Cotton Research Officer formerly stationed in St. Vincent and currently in Antigua.

Mechanization. In the field of advances in mechanization the introduction of new types of machinery for agricultural operations and, here and there, the centralization of processing have contributed materially to progress in the industries which have been able to take advantage of them, and, as remarked above, the credit for such advances must be divided between the management of the larger agricultural enterprises and local engineering firms. Yet it would be incorrect to suggest that advances in mechanization have been either uniform or really extensive. Much of what is available cannot be used profitably by the small cultivator (though land-clearing or heavy tillage equipment may sometimes be available on hire), and even in the sugar industry, which is that most affected by this type of development, the survey made by the Caribbean Commission in 1947 could record 'only limited progress . . . in respect to the mechanization of cultivation'.

Fertilizer use. In the above-mentioned crop survey, the writers considered that 'great progress has been made . . . in the use and application of fertilizer'. The consumption of fertilizers has unquestionably risen, and, especially in the sugar industry, investigation of the manurial requirements of the sugar-cane has been in progress throughout the period under review. A few of the larger sugar companies can point to substantial progress, but, these apart, the effectiveness of the applications of fertilizers has been none too impressive. Among smaller producers insufficient use may have been made of fertilizers, but the most significant feature is the inability of the grower to control changes in the physical environment once planting is completed. Even when fertilizer is applied to the soil in quantities representing a calculated amendment of nutrient status, its uptake by the crop may be, and often is, seriously impeded by unfavourable physical conditions. In

export crops other than sugar-cane this consideration applies with equal or even greater force, and no large advance in the effective control of crop nutrition can be recorded.

Pest and disease control. In the realm of pest and disease control a balance must be struck between the effectiveness of a treatment, the extent to which it is used, the economic importance of the crop which it benefits, and the possibilities which the treatment offers of further exploitation. On this basis a claim may be made for a specific advance in the field of biological control, and for another in that of agronomic control, and for a general comprehensive advance in the use of chemicals for crop protection. A substantial measure of success for biological control can be claimed for the sugar-cane moth-borer campaigns in British Guiana, St. Lucia, St. Kitts, and Antigua (mentioning only British territories). Success, too, can be claimed for the adoption, in Jamaica and the Windward Islands, of the 'bare-root' system of citrus growing, a protective measure both against the most serious type of attack by larvae of 'citrus-weevils' and against 'collar-rot'.

Both these advances have called for little expenditure or effort on the part of the grower. In contrast, the use of modern insecticides, fungicides, or weed-killers involves a very appreciable outlay on materials and repeated effort in application and maintenance, and this consideration has undoubtedly been paramount in determining the extent to which methods of chemical control of pests and diseases have been adopted. The newer insecticides and fungicides, especially the former, can claim a place among agricultural advances in most countries of the world. In the West Indies their use has led to a number of local successes, but these, even in sum, perhaps only just qualify as representing an outstanding advance. Their use has possibly already nearly reached its final level, and there is room for doubt whether some insecticidal treatments will continue to be as effective as hitherto. The grower must feel well assured of the economic value of the results before he adopts a pesticidal or fungicidal routine. Nevertheless, in a few directions, there is general agreement on what ends are best served by such means: perhaps the most important are the control of leaf-spot in bananas throughout the Caribbean area, and the control of the sugar-cane froghopper and of leaf-cutting ants in Trinidad, British Honduras, and the mainland areas between them.

Evaluation of Progress and Future Prospects

The developments listed above, with few exceptions, represent the practical application of scientific work, and by reason of their widespread occurrence in the area must be considered outstanding in relation to lesser advances. But are they really of the first significance? Indeed, does this approach of listing 'practical results to date' with its emphasis on tangible and widespread success, truly reflect the progress of agricultural science in the West Indies, or give any hint of how far progress has been made in meeting the fundamental need?

The economic precariousness of West Indian agriculture is attributable more to low productivity per acre than to low market prices or any

other factor, and this applies both to crop and livestock products. Have the advances cited above led to any marked and apparently permanent change in this position, at least as far as export crops are concerned? The broad answer must be in the negative. Yet one advance which materially affects the question of productivity has been in progress for many years, and constitutes an asset, though as yet unrealized in practical application, of momentous significance. It is the elaboration of techniques for following the requirements, nutrient or physical, of West Indian crops throughout their annual cropping cycle, and for rapidly adjusting discrepancies to a predetermined standard level.

Here and there, in various parts of the world, procedures which involve the periodical assessment of nutrient status of the crop, and, in some places, of water deficit, have been used in the sugar industry and have abundantly proved their value. They have been introduced into the West Indies relatively recently and the results have clearly demonstrated that this approach, in local conditions, is as helpful as it has been elsewhere. Use of such methods, however, has not yet extended outside a few of the larger companies.

The technique of tracing the changes in nutrient level in the plant provides one part of the data needed for elaborating an effective agronomy, irrespective of the crop involved, and for this reason is not only a normal tool in the programmes of agronomic research at the Imperial College of Tropical Agriculture, but has reached the stage at which, with appropriate organization under Government, a service to the agricultural industries could rapidly be set up.

The other part of the data needed for devising an effective agronomy, however, is at present by no means so easy to obtain. This part refers to the way in which each plant, at each particular spot, is affected by weather, notably by sunshine and rainfall. Since, in some crops, notably tree crops, use of data of the first kind is very seriously limited in the absence of such environmental data, attention has been focused on devising methods of obtaining the wanted facts, but it is only very recently that methods of overcoming the difficulties have begun to suggest themselves. The practical application of such knowledge, where it is already sufficiently available, is still in the experimental stage; in most crops the basic data are still insufficient, and are being sought, or have yet to be sought. Activities so restricted in present popularity, or so embryonic in their degree of development, cannot be claimed as an outstanding advance on a regional basis. But the fact that they point the way from soil-degrading agronomies to a permanent agriculture, and from the resigned acceptance of low yields to intensive cropping, encourages the view that they presage the greatest advance of all. The gratifying results so far obtained by the exponents of such methods in the local sugar industry serve both to remove fears that the effectiveness of this line of approach is overestimated, and to justify the amount of attention it is receiving in the programmes of the B.W.I. Regional Research Centre at the Imperial College of Tropical Agriculture.

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WATER CONSERVATION BY FALLOWING IN SEMI-ARID TROPICAL EAST AFRICA

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Summary

Crop yields and soil-moisture changes to 6-ft. depth were measured in two cycles of five 2-year groundnut rotations. Fallows kept bare, sown with protective grass cover, and allowed to regenerate volunteer weeds and grasses were compared with maize and with sorghum in alternate-year cropping with groundnuts. Soil-moisture-tension changes were followed by gypsum blocks and quantitative changes were measured by soil sampling.

Measurements were made of the root ranges at different growth stages of groundnuts, maize, sorghum, and teff; all lay within the 6-ft. depth.

Annual rainfall totals for the four years of the experiments were 22, 8½, 13, 13 in. respectively.

The volunteer cover removed all available water from 6 ft. and used more water than maize, sorghum, or groundnuts. Bare fallow conserved water and increased subsequent yields of groundnuts, but no fully satisfactory soil conservation measures were achieved.

Protection of fallow by a heavy sowing of 'teff' grass provided efficient soil conservation and, with a seed-rate of 20 lb. of viable seed per acre, suppressed weeds and stored subsoil moisture. Groundnut yields of over 400 lb. kernels per acre were thus secured in a year of 8·5 in. total annual rainfall.

BETWEEN 1947 and 1951 the Overseas Food Corporation (O.F.C.) Groundnut Scheme at Kongwa cleared from dense Commiphora thicket and partly developed some 100,000 acres of land in the dry plains of Tanganyika Central Province. By 1951 crop failures due to drought led to the abandonment of the original production programme. The Scheme was then taken over by the Tanganyika Agricultural Corporation (T.A.C.) with new objectives. These combined a large-scale development of ranching with the use of part of the arable area for pilot experiments in the techniques of mechanized dry-land agriculture.

The strong scientific team built up by the O.F.C. at Kongwa had carried out energetic programmes of soil survey and agronomic research in the years 1947–51. In the latter programme, while great attention had been given to fertilizer experiments, comparatively little attempt had been made to measure the water relationships of crops in this harsh agricultural environment. A useful exploratory comparison was, however, made in 1950 between the dry-season water contents of complete soil profiles under undisturbed thicket and under continuously cropped arable land. No significant differences were found, and the conclusion

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was reached that subsoil moisture was unlikely to accumulate under arable cropping. Investigations into moisture accumulation by bare fallows were therefore noted as necessary for future work [1]. Some preliminary observations with gypsum blocks ran into difficulties due to soil salinity, but useful information was obtained when a rotation experiment was abandoned and a failed grass ley gave an effective bare fallow. This resulted in a substantial and significant increase in groundnut yields in the following year. The increase was probably due to water conservation [1]. As a result of the foregoing observations Bunting [2] advocated the use of bare fallow rotations for soil moisture conservation.

In 1952 responsibility for directing and assisting in the specialist fields of agricultural research work of the T.A.C. was undertaken by the East African Agriculture and Forestry Research Organization (E.A.A.F.R.O.). A detailed joint study of the water relationships of fallows in crop rotations was begun immediately and is reported here.

Object of Experiments

1. To seek improvement in the reliability of arable cropping, under conditions where land is plentiful but rainfall is both scarce and erratic, by fallowing to store water in the subsoil.
2. To measure the water use of arable crops and the accumulation of water in both bare and protected fallows.
3. To test methods of protection of bare fallows from erosion.

Vegetation, Soils, and Climate

The experiments were sited on the most important and extensive of the Kongwa soil types, surveyed by Anderson and named the 'Chamaye' series of sandy red loams of high fertility [3]. These are 'mantle' soils of transported material derived from Basement Complex horneblende-gneiss. Soil depths were checked by digging pits around the experimental area, which showed uniform profiles with no visible horizons other than a stone-line at 6 ft. Total soil depth was 8 to 10 ft. The location, altitude 3,650 ft., latitude S. 6° 02′, longitude E. 36° 20′, is climatically typical of a very great area of semi-arid African territory. The natural vegetation is very dense Commiphora thicket, leafless in the dry season, with scattered baobab trees (*Adansonia digitata*) and some *Acacia spirocarpa*. Grasses were confined to old lake beds or *mbugas*.

The rainfall is confined to a single season from December to May, and is followed by six months of complete drought. The erratic distribution within the season is a major difficulty in establishing arable crops. Glover, Robinson, and Henderson [4] have shown the expectation of 20 in. or more rainfall to be less than seven years out of ten. Readings of the O.F.C. grid of some fifty rain gauges at 2-mile intervals are available for the wet seasons of 1950, 1951, 1952, and show wide variations in the rainfall received by adjacent gauges. These differed in some cases by over 2 in. on a single day, and by 8 in. in a season. The mean annual rainfall 1949–56 in the area of these experiments was approximately 17 in. Air temperatures in a Stevenson screen exceeded 90° F. in the hottest months, October/November. The annual mean air temperature

at Dodoma (14 years) is 72° F. Open-water evaporation from a 4-ft. diameter sunken insulated pan averaged 83 in. per annum and reached a monthly total of 10 in. in November.

Treatments and Methods

Design of Crop-rotation Trial

A field trial in the form of a 5×5 Latin square with $\frac{1}{10}$-acre plots was laid down with the following treatments: bare fallow, protected fallow, volunteer cover, maize, sorghum. These five treatments were given in the first year of the rotation, while groundnuts were grown in the second year. Two complete cycles of these five 2-year rotations were studied, so that the treatments were given in 1952 and 1954 while groundnuts were grown in 1953 and 1955.

The bare fallow was kept clean-weeded by frequent cultivation. The protected fallow was given a very heavy sowing of teff (*Eragrostis abyssinica*) at the seed rate of 90 lb. per acre in 1952. Germination percentage was 18·5 per cent. in 10 days. Nearly double this amount of seed was subsequently harvested. In 1954 the sowing rate was reduced to 45 lb. per acre; in 1955 a small supplementary trial comparing different seeding rates was conducted. The maize was planted at a spacing of 18×34 in., while the sorghum was planted at 9×34 in. One-half cwt. of triple superphosphate per acre was applied at planting time in 1952 and 1953 and 1 cwt. per acre was given in 1954 and 1955, the fertilizer being broadcast before tractor-disking of the whole experiment.

The plots were laid out on the contour on a uniform 2 per cent. slope, which gave no difficulties with plot shape; all cultivations followed the contour. In the first rotation broad ridges were used as advocated by Bunting [2], while in the second rotation, for reasons given below, smaller tied ridges were used.

Soil Moisture Measurements

The pattern of distribution and movement of soil moisture in the profile was established by the use of gypsum resistance gauges as indicators of soil-moisture tension, while quantitative data were obtained by periodic soil-moisture sampling to 6 ft. depth. Duplicate profile sets of moisture gauges were places at 1 ft. intervals to 6 ft. depth in all five treatments. The resistance gauges were cast in the laboratory using a simple and cheaply made cylindrical design based on the Bouyoucos block [5], but modified in order to minimize the external path of the metering current. Details of construction are given in Appendix 1. The resistances were read by an alternating current hand-driven B.T.L. ohmmeter designed for work in African field conditions [6].

Volumetric Calibration of Soil Water Storage

Five pits were sunk to the parent rock around the experimental area. From the sides of the pits vertical cores 3 in. deep and 4 in. diameter were taken at 1 ft. intervals to 6 ft. The cores were vacuum-wetted and then brought to equilibrium at successive tensions of 10, 50, 100, and

330 cm. of water. The core sampling tool, the laboratory methods, and equipment used in handling the cores are described elsewhere [7]. The volume-weights from these cores were used to convert the gravimetric moisture data to inches depth of water per foot depth of soil.

Root ranges

Root ranges of the developing crops, herbs, and grasses were studied by washing-out of root systems on extra guard rows, using a motor-driven pump. A botanical analysis was made of the volunteer vegetation on the uncultivated fallow, and the list of species identified is given in Appendix 2.

Soil temperatures

Since the loss of water in both bare and protected fallows is a function of the temperatures reached under tropical isolation, soil temperatures were observed by mercury-in-steel thermographs with horizontal bulbs placed at 1, 2, and 3 in. depth in the bare fallow, and also at 1 in. depth under short grass and under tall grass.

Rainfall

Rainfall was averaged from four 5-in.-diameter rain gauges sited within the 4 acres containing the experiment.

Evaporation Factors

A meteorological screen and a Robinson's anemometer at 6 ft. above ground level were read on the site of the experiment, and were used to verify that conditions were similar to those of the Kongwa Experiment Station, some 20 miles away in the same plain, in order to make use of the more detailed equipment there available. At the Experiment Station a sunken insulated evaporation pan 4 ft. in diameter, a Campbell-Stokes sunshine recorder, and a Robinson's anemometer at 6 ft. above ground level were read daily, together with thermohydrograph and thermometers in a standard meteorological screen.

Results

Water-storage Capacity of Soil Profile.

The cores showed very little variation in real and apparent soil densities of successive horizons, and the mean results for each 1 ft. depth were used to convert the moisture sampling data into equivalent inches of rain. The pore-space distribution fluctuated considerably with depth as is to be expected from the data for mechanical analysis. (Table 1). The average pore-space results for the 6 ft. profile are set out in Fig. 1. The tension determinations on soil-cores wetted under reduced pressure to release entrapped air showed that this first 6 ft. of soil could hold a maximum of $35\frac{1}{2}$ in. of water at a tension of 10 cm. This would drain very rapidly in 24 hours to about 23 in. of water (at 100 cm. tension), and more slowly in three or four days to 20 in. of water at $\frac{1}{3}$ of an atmosphere tension. These are limiting maximum values which the soil

TABLE 1. *Average Mechanical Analyses of Kongwa Red Soil at the site of the Fallowing Experiments*

Depth	*Sand* > 0·02 mm.	*Silt* 0·02 mm. to 0·002 mm.	*Clay* < 0·002 mm.	*Moisture air-dry soil*
0 to 6 in.	72·3	4·0	22·1	1·6
At 3 ft.	57·5	12·1	27·7	2·7
At 6 ft.	74·1	16·0	7·0	2·9

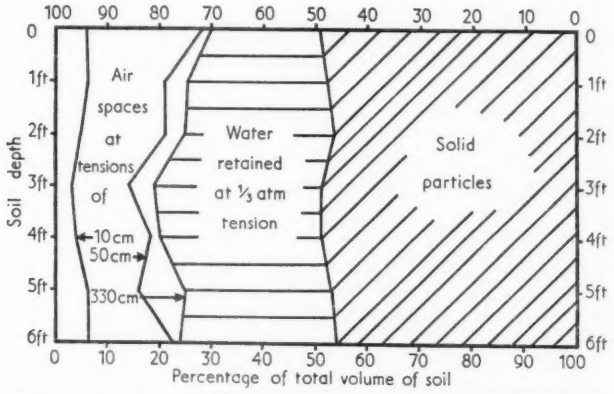
100 90 80 70 60 50 40 30 20 10 0
0 1ft 2ft 3ft 4ft 5ft 6ft
Soil depth
Air spaces at tensions of
10cm
50cm
330cm
Water retained at ⅓ atm tension
Solid particles
0 10 20 30 40 50 60 70 80 90 100
Percentage of total volume of soil

FIG. 1. Average six-foot soil-profile data for Kongwa fallowing experiment.

moisture sampling subsequently showed to be substantially beyond those reached in the field under bare fallow. The difference is caused firstly by the entrapping of air which prevents the soil from reaching full saturation. Secondly, the soil profile does not reach equilibrium at field capacity at all depths simultaneously. As a result the maximum water found by sampling in the fallow plots was 16·9 in. and the usual value for wet conditions was about 14 in. Thus the rainfall was inadequate, in the years of the experiment, to permit full use of the soil's storage capacity within the root range of the crops.

Root Ranges of Crops

Maize. Initial root development was very rapid, depths of 12 in. being attained within the first 3 weeks after planting. A dense system of lateral roots was formed, which spread horizontally from 12 to 18 in. round the plants before turning down; these eventually reached depths of 5 ft., but did go below 6 ft. by the end of the growing season (Plate 6).

Sorghum. Root development was at first much slower than in maize but increased markedly as the season progressed and the plants started

tillering. Most of the major roots began as laterals near the surface and then grew vertically downwards attaining depths of up to $5\frac{1}{2}$ ft.

Groundnuts. As with maize and sorghum, secondary roots were traced to depths of between 5 ft. and 6 ft. but with the bunch variety grown lateral spread was negligible (Plate 6).

Teff. Main root development was in the first foot, with the greatest concentration to a depth of 6 in., though a considerable scattering of roots was found to a depth of 2 ft. at the end of the growing season.

Volunteer cover. A breakdown of the only available motor pump brought this work to a halt before the root-systems of the volunteer cover could be examined. Both soil-moisture sampling and resistance-unit records showed that the soil was dried out fully to wilting point at the 6 ft. depth in the years 1952 and 1954 in which this cover was allowed to develop.

These results confirmed, for the crops and soils of this experiment, earlier findings for the same district and soil type by Lea [8], who reported the vertical root-ranges of fully developed groundnut, maize, and sorghum crops to be from 5 to 6 ft.

Rainfall and Crop Yields

1952. In the first year a very good rain season of 22 in. gave high yields; 3,500 lb. of grain per acre were harvested from the maize plots and similar yields were obtained from large-scale O.F.C. plantings. A heavy crop of sorghum was entirely stripped by birds before any estimate of yield was obtained. Much of the large-scale O.F.C. plantings met a similar fate. The teff produced a dense cover and a heavy seed crop of approximately 200 lb. per acre was harvested 60 days after sowing. An effective cover of volunteer grasses and herbs was also obtained.

1953. A badly distributed rainfall amounting to only 8·5 in. for the year caused widespread crop failures in the Kongwa area. This severe drought emphasized the value of stored soil moisture, both in crop establishment and in subsequent yield. The effects are summarized in Table 2. The first sowing of groundnuts germinated but died of drought. Striking differences in the percentage survival one month after planting were observed. The crop was resown on 6 February. The stored water continued to assist in plant establishment and improved the final plant population. The crop was dominated by the pattern of 'broad lands', since the rows nearest the furrows benefited by surface runoff, while those on the ridges were handicapped by loss of water. This effect was most noticeable where reserves of stored soil moisture were lowest and yields were very heavily affected, as is shown by Table 2. This 'broad lands' system, familiar in Europe on heavy wet land, proved successful in the O.F.C. Scheme at Urambo, where drainage is a problem, but was never adopted by the production farms on the Kongwa Scheme, where the problems were of drought rather than of drainage. For the second cycle of these experiments tied ridging was therefore substituted, using tractor-mounted potato-ridging tools.

Table 2 shows that the use of either bare or teff-protected fallow in the first year effectively doubled the yield of groundnuts in the second year.

The teff provided complete protection from both wind and water erosion without subsequent loss of crop. The safe achievement of a crop yield of over 400 lb. of groundnut kernels on a total annual rainfall of 8·5 in. is of considerable promise for semi-arid agriculture.

TABLE 2. *Effects of Stored Soil Moisture on Survival Rates and Yields of Groundnuts in 1953*

	Treatments in previous year					*Least significant differences at P = 0·05*
	Bare fallow	*Teff fallow*	*Volunteer cover*	*Sorghum crop*	*Maize crop*	
Water stored from 1952 in 6 ft. of soil (in.) .	12·7	12·3	9·2	9·4	10·0	0·8
First planting Survival at 1 month (%)	42	44	5	32	16	21
Second planting Survival at harvest (%)	55	53	40	40	41	16
Yield of kernels						
Inner rows (lb. per ½ acre)	139	144	65	34	43	143
Outer rows ,,	271	338	186	173	173	
Whole crop (lb. per acre) .	410	482	251	207	216	203

1954. Although this rain-season started well, a severe attack of 'Army Worm' (Larva of *Leucania unipuncta*) destroyed the early crop. Maize and sorghum were resown on 3 February and produced full plant populations, giving fair yields of 1,303 and 1,291 lb. grain per acre respectively, on a total rainfall of 13·3 in. The teff seeding rate was reduced to 45 lb. per acre. This proved inadequate, since it permitted the fuller growth of both tops and roots, while weed-control was less effective.

1955. Groundnuts were sown at the end of January. A favourable rainfall distribution resulted in a full stand of plants which grew well. A dry spell in the third week in April was observed to cause wilting on all plots except those previous bare fallowed. Heavy damage by elephants caused the loss of yield results on one complete replication. The average yield of groundnuts was 763 lb. kernels per acre on a total rainfall of 13·2 in.

Table 3 shows the treatment yields, together with the stored soil moisture at planting time. It is clear that the teff at the lower seeding rate used in 1954 had behaved more like a cereal crop in its water requirements which were equal to those of maize but less than those of sorghum. This is reflected in the 1955 groundnut yields.

While water storage by bare fallow again produced a substantial increase in yield the groundnuts following teff yielded 204 lb. per acre less than those after bare fallow. The apparent improvement in yield after teff as compared with maize and volunteer cover did not reach the 5 per cent. level of significance.

TABLE 3. *Effect of Stored Soil Moisture at Planting Time on the Yield of Groundnuts in 1955*

	Bare fallow	*Teff fallow*	*Volunteer cover*	*Sorghum crop*	*Maize crop*	*Least significant difference at* $P = 0.05$
	(in. of water in 6 ft. of soil)					
Water stored from previous year .	13·8	11·6	10·2	10·5	11·5	1·02
	(lb./acre of kernels)					
Groundnut yields	1,053	849	649	547	715	227

Seasonal Distribution of Soil Moisture

Fig. 2 summarizes both the rainfall and the cropping histories of these rotations, together with the consequent distribution of soil moisture in depth and time. This distribution is obtained by plotting the log-resistance of gypsum moisture gauges. These give reliable information as to the exhaustion of available soil moisture and the attainment of wilting point. Under wet conditions they are insensitive to low soil moisture tensions, but have a threshold value of approximately 1 atmosphere for their initial change of resistance. Such changes therefore indicate drying by evapotranspiration only, with reliable assurance of the cessation of downward drainage. Detailed calibration to soil-moisture content of individual gypsum gauges has been tested in East African conditions, but has been found to be uneconomic for the numbers required in field trials [6, 9]. In these experiments they have been used to supplement a well-replicated soil-sampling programme. The shaded areas in Fig. 2 therefore show with useful accuracy the times and depths at which the soil-moisture tension reached the approximate limits of 1 and 15 atmospheres. The curves joining these points outline the conditions of water availability between these limits with sufficient accuracy, the relation of log-resistance to pF being linear [10].

Fig. 2 affords the following direct information:

(1) Both bare and protected fallows stored water between the 2nd and 6th foot depth. By the end of the dry season in 1952 there was little apparent difference between the distribution of available water under the bare fallow and that under the fallow protected by teff. Little of this stored water was used by the very poor crop of groundnuts in 1953, but nearly all of the stored water from the 2nd, 3rd, and 4th ft. in both treatments was used by the more successful groundnut crop of 1955. At the end of the 1954 dry season the lighter seeding rates, and hence deeper root range of the teff, had dried out the second foot completely, but substantial quantities of stored water are indicated in the 3rd to 6th ft.

(2) In the volunteer cover rapid root growth and efficient exploitation of soil moisture by the grasses and herbs indigenous to these dry plains

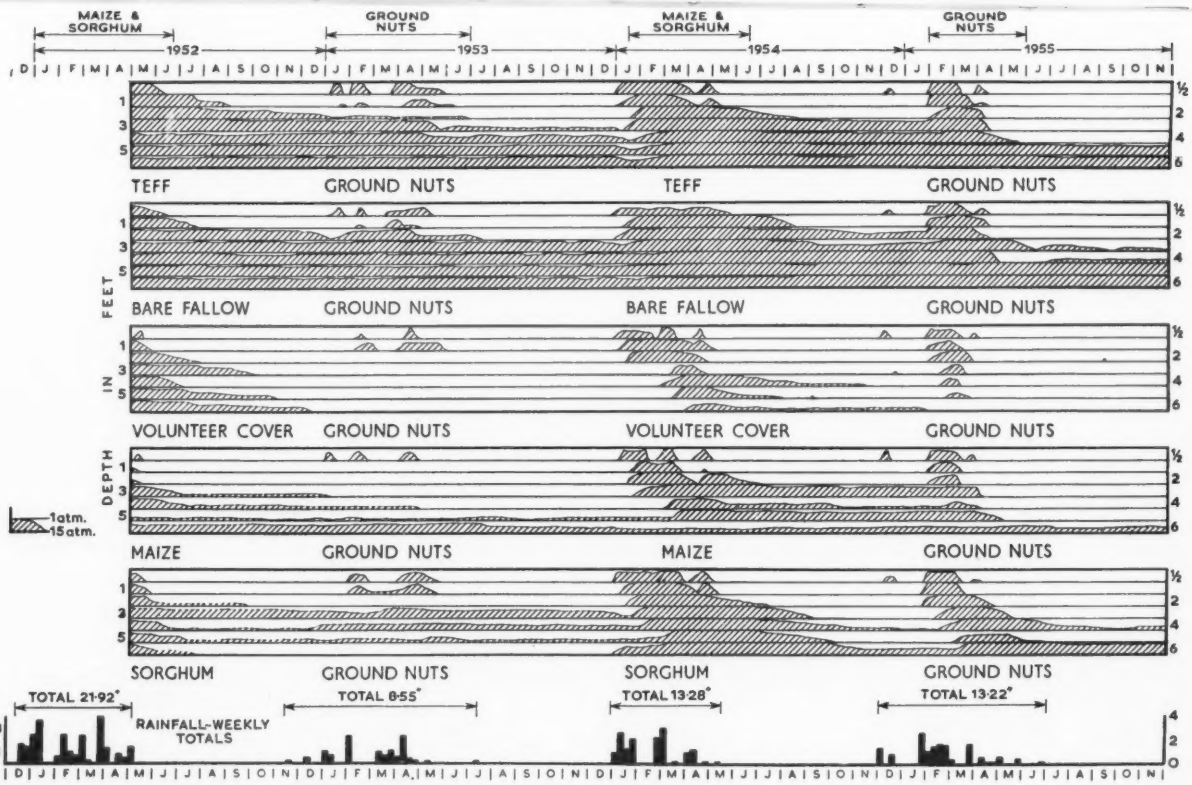

FIG. 2. Soil Moisture Distribution in Five Two-year Groundnut Rotations

The shaded areas represent availability of water to plants, between the one-atmosphere and wilting-point limits.

reduced the whole 6-ft. soil profile to wilting point in both years. Falling on such dry soils, the very poor rains of 1953 failed to penetrate even to the second foot, while in 1955 although reaching a depth of 5 ft., the rainfall was insufficient to support a useful crop.

(3) The maize crops of 1952 and 1954 both failed to dry out the profile completely while the sorghum used as much water as did the volunteer cover in these years. This is in part due to the tendency of sorghum stubble to regrow; Fig. 3 shows clearly that such transpiration after harvest drew on water stored in the 4th to 6th ft. depths.

Quantitative Measurements of Seasonal Soil Moisture Changes

Sampling to 6 ft. in dry soil conditions offered considerable difficulties in this soil type when hand augers were used. In the second year heavily weighted drill-rods were employed with a capstan suspended by cable from a light tubular steel frame equipped with a winch. Regular sampling continued with this equipment until the end of 1955. The soil samples were weighed in a caravan at the site, and then sealed and despatched to E.A.A.F.R.O. laboratories for oven-drying. A mechanical failure of the drill frame in 1953 could not be repaired before the rains arrived in November and the driest profile conditions for this season were therefore not measured.

The sampling data are too numerous to set out in full, but they afford useful confirmation of the soil moisture availability described by Fig. 2. A summary of the wettest and driest conditions found in each season for each of the five rotations is given in Table 4. In spite of the increased volume of foliage and higher yield of the groundnut crops after both the bare and the teff-protected fallows, the residual water stored at the end of two rotations was a little greater than that found after the sorghum or volunteer-herbage rotations. No significant interaction was found in moisture contents at the end of the dry season between treatment and depth, the stored water lying between the 3-ft. and 5-ft. depths in all plots.

The complete failure of the poor rains of 1953 to rewet the profile, already described by Fig. 2, are fully confirmed by Table 4, the wettest conditions of the soil in 1953 showing in all treatments gains of less than 2 in. over the amount left from the 1952 dry season.

The protective sowing of teff, using the very heavy seed rate in 1952, resulted in these plots holding 3 in. more water than those which had been under volunteer cover or sorghum. The halving of the seed rate in 1954 permitted greater development of the teff roots and tops, so that the water stored, although significantly better than volunteer cover or sorghum, amounted only to 1 in. It was equalled, unexpectedly, by the stored water left by the maize crop.

Sowing Rates for the Protective Grass Cover

The very favourable results from the teff-protected fallow in the first cycle of the teff rotation were obtained with the heavy sowing rate of 90 lb. per acre although less than 17 lb. of this was viable seed. This

TABLE 4. *Maximum Seasonal Changes in Soil Water Storage (inches of water in 6 ft. of soil)*

Rotation	*Year*	*Wettest soil condition*	*End of dry season*
CYCLE I. 1952: rainfall 21·9 in. 1953: rainfall 8·6 in.			
Bare fallow	1952	16·4	12·7
Groundnuts	1953	13·3	..
Teff-fallow	1952	13·3	12·3
Groundnuts	1953	12·8	9·4
Volunteer cover	1952	14·5	9·2
Groundnuts	1953	10·9	..
Sorghum	1952	15·9	9·4
Groundnuts	1953	11·1	..
Maize	1952	14·7	10·0
Groundnuts	1953	11·3	..
CYCLE II. 1954: rainfall 13·3 in. 1955: rainfall 13·2 in.			
Bare fallow	1954	16·6	13·8
Groundnuts	1955	16·7	11·7
Teff-fallow	1954	16·9	11·6
Groundnuts	1955	14·7	11·6
Volunteer cover	1954	13·7	10·2
Groundnuts	1955	14·2	10·9
Sorghum	1954	15·4	10·5
Groundnuts	1955	14·8	10·8
Maize	1954	16·1	11·5
Groundnuts	1955	16·4	11·3
Least significant differences at P = 0·05	1952	1·09	0·80
	1953	0·85	..
	1954	0·94	1·02
	1955	1·74	0·83

heavy seeding was given in order to restrict root range by the establishment of an overcrowded plant population and also to smother volunteer species which would root more deeply. In 1954 the seed rates were halved, and the water conservation was less effective. This dependence on seed rate was further studied in a subsidiary experiment in 1955, using seed of 25 per cent. germination rate. In this experiment soil-moisture sampling was carried out on a 4×4 Latin square of large plots sown with teff at rates of 0, 15, 30, and 45 lb. per acre. The bare plots were kept weed-free and protected by tied ridges; no weeding was done on the sown plots, but weed-counts were taken. The results are given by Table 5. In 1955 the total rainfall of 13·2 in. was inadequate to recharge the soil storage to field capacity. The bare fallow retained about $1\frac{1}{2}$ in. more water than the teff plots, while the latter showed no significant effect of sowing rate. The extra water in the bare fallow lay in the first

3 ft. and half of it had been lost after 2 months of dry weather, while only ½ in. remained at the end of the dry season. Weeds were not effectively controlled by the teff at these seed rates and it is clear that very heavy sowing rates of the order of 100 lb. of seed per acre (i.e. 20 lb. of viable seed per acre) are needed for successful water conservation. Teff has been used in these experiments because seed is available in commercial quantities, and something is known of its characteristics as a crop. The use of more ephemeral and shallow-rooted grasses appears to be worth further testing. A local pioneer grass dominant on abandoned arable is *Dactyloctenium aegyptium*. This appears to have suitable properties and further studies to compare the water relations of this grass with those of teff have already begun. *Setaria italica* may also prove to be a useful alternative.

TABLE 5. *Water Use of Protective Sowings of Teff on Fallow*

Treatment	*A*	*B*	*C*	*D*	
Sowing rate . .	Nil	15	30	45	lb. per acre
Plant establishment .	Clean fallow	220	250	466	Teff plants per square foot
Weed count . .	Nil	5·8	5·0	4·6	Average weeds per square foot

Soil Moisture in Inches

(*in a seasonal rainfall total of 13·2 in.*)

					Significant differences
End of rain (*April*)					
0–3 ft. . . .	6·5	4·8	5·1	4·9	$A > B, C, D$ at $P = 0.001$
3–6 ft. . . .	5·4	5·5	5·2	5·7	None
0–6 ft. . . .	11·9	10·3	10·3	10·6	$A > B, C, D$ at $P = 0.01$
Early dry season (*August*)					
0–3 ft. . . .	5·2	4·4	4·3	4·2	$A > B, C, D$ at $P = 0.01$
3–6 ft. . . .	5·7	5·2	5·3	5·5	None
0–6 ft. . . .	10·9	9·6	9·6	9·7	$A > B, C, D$ at $P = 0.01$
End of dry season (*November*)					
0–3 ft. . . .	4·6	4·2	4·0	4·1	$A > B\ C, D$ at $P = 0.05$
3–6 ft. . . .	5·5	5·3	5·1	5·3	None
0–6 ft. . . .	10·1	9·5	9·1	9·4	None

Soil-conservation Measures and Infiltration Rates

The mechanical protection of bare fallow by ridging was attempted in two forms. In 1952 the fallow was ploughed into 'broad lands' approximately on the contour, being parallel to the original contour banks formed during the mechanized bush clearing. The large capacity of the

broad shallow furrows thus formed served to concentrate drainage water into the low places which inevitably occur when ploughing parallel to 'master-contours' and serious local gullying occurred where this broadlands ridging was used on a large area. No gullying occurred on the plots since the lands therein were set up more accurately. Even with this accurate broad ridging, however, the shedding of water from the ridges resulted in the very uneven crop growth and yield already described.

TABLE 6. *Bare Fallow Effects on Pore Space of Surface Soil*

Free-draining pore-space as percent total apparent volume of soil; tensions in cm. of water

Drainage tension	*10 cm.*	*50 cm.*	*100 cm.*
Bare fallow . . .	7·4	22·0	25·7
Crops and grasses . .	11·5	26·1	28·1
Least significant differences at P = 0·05 . . .	4·1	5·2	4·9

After harvest twenty-five surface cores 4 in. diameter and 3 in. deep were taken using a sleeved sampler with a 10-lb. sliding hammer falling 1 ft. [7]. Table 6 suggests that even in one season of bare fallow there was a small reduction in the volume of the large pore-spaces which are critical for percolation rates. Experience in East African soils shows that such structure deterioration by clean cultivation develops with cumulative effect in successive seasons [11]. The number of cores was too small to obtain significance for the remaining differences, or for differences in percolation rates. A high mean rate of 6·6 in. per hour was obtained for percolation under a static head of 1 cm. of water.

In 1954 small ridges made with potato equipment were hand-tied at 3-ft. intervals. During the rains water lay in many of the tied basins and produced a surprisingly severe hardening effect on the soil to a depth of between 2 and 3 in. Cores taken from basins in which water had lain required 435 blows to drive the heavy cylinder 4 in. into the soil as compared with only twenty-five blows for the broad-ridged fallow. Percolation rates are not fully reliable on cores taken by so prolonged a hammering, but averaged 4·2 in. per hour for ten cores, compared with 6·6 in. per hour for the broad-ridged fallow.

Acceptance of heavy artificial rainfall by the cores was very poor. Using an equipment delivering 1 in. of rainfall in 10 minutes as drops of 6 mm. diameter [12] infiltration averaged only 0·31 in. The capping of the soil surface under heavy rainfall reduced infiltration to well below the percolation rate. The hardened soil from the tied basins (after vacuum wetting) showed no apparent reduction in this rate of rainfall acceptance.

This hardening of disturbed sandy soils when water lies on the surface is an effect of serious concern for mechanized agriculture, and difficulties were met on the Kongwa farms in ploughing soils which had lain submerged adjacent to the contour banks.

Soil Temperatures

The severe desiccation during the dry season is well illustrated by the temperatures reached beneath the surface of bare soil. A brief summary of results from mercury-in-steel thermographs with bulbs set horizontally so that their axes lay 1, 2, and 3 in. respectively below the bare soil surface, is given in Table 7 with results from thermographs at 1-in. depth below short grass and tall grass. The heat-insulating effect

TABLE 7. *Effects of Grass Covers on Soil Temperatures*

Means of daily maximum soil temperatures in °F. (Data for one complete year, from 1 November 1954 to 31 October 1955)

Surface cover	*Bare soil*			*Grass 2 in. high*	*Grass 10 in. high*
Thermometer depth .	1 in.	2 in.	3 in.	1 in.	1 in.
Annual means (°F.) .	107·6	95·8	86·0	86·4	77·9
Highest monthly means (°F.) . . .	121·6 Oct.	107·4 Oct.	94·4 Nov.	95·4 Jan.	86·8 Jan.

of the dead stems of ephemeral annual grasses is very substantial, although much of this type of grass protection is lost through the native custom of annual burning. A discussion of the full 3 years' data on soil temperatures will be published separately.

Discussion

The difficulties of protecting tilled bare soil from erosion when it is exposed for long periods renders bare fallowing a dangerous and inappropriate technique for East African conditions. Neither broad lands nor tied narrow ridges provided a satisfactory solution. The protection of fallows by the sowing of a quick-growing, short-season, annual grass of shallow-rooting habit offers a logical alternative which has been tested in detail in these experiments. The results illustrate an agricultural technique for 'dry-farming' in the Kongwa area which is satisfactory from the important aspect of soil conservation and of crop yield. The practical economics of such a protected-fallow rotation on a full farming scale have not yet been tested since the completion of these studies coincided with the cessation of arable cropping operations by the Tanganyika Agricultural Corporation.

The crop yields were increased by from 30 to 100 per cent. by fallowing, but cultivation areas were thereby doubled. Since all planting and sowing must be achieved in the course of approximately 2 weeks, if optimum yields are to be obtained, the need to clean and sow with teff an additional arable area equal to the total area cropped must involve the provision of more tractors, equipment and personnel. The annual depreciation charges on such a large tractor fleet are very heavy in proportion to the hours worked.

The basic advantage of increased reliability of yields, is, however, in itself of the greatest economic importance when achieved with efficient soil and water conservation.

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APPENDIX 1

Grasses and Herbs Volunteering on Weedy Fallow

These species produced a dense cover.

Grasses

Aristida adscensionis (occasional)
Brachiaria serrifolia and other sp. (common)
Chloris virgata (common)
Cynodon plectostachyum (rare)
Dactyloctenium aegyptium (common)
Digitaria velutina and other spp. (common)
Eragrostis aspera (common)
Eragrostis cilianensis (present)
Leptocarydion vulpiastrum (common)
Panicum maximum (common)
Rhynchelytrum repens (v. common and dominant on some plots)
Setaria pallidefusca (present)
Sporobolus panicoides (occasional)
Tragus sp. (occasional)
Urochloa trichopus (common)
Urochloa spp. (occasional)

Herbs

Amaranthus sp. (present)
Commelina spp. (common)
Convolvulus spp. (common)
Crotalaria spp. (v. common)
Hibiscus mastersiamus (common)
Ipomoea sp. (common)
Leonotis sp. (fairly common)
Solanum panduriforme (common)

APPENDIX 2

Electrical Soil Moisture Gauges used in these Experiments

When these field trials were designed, gypsum resistance units were not immediately available from sterling sources in the numbers required, while currency difficulties precluded importation of Bouyoucos Blocks. The laboratory manufacture of some

200 units was therefore undertaken in order to avoid missing a cropping season. Where research staff are extremely few in proportion to the problems to be studied, hand production of equipment already available in commercial forms is basically uneconomical; the details are, however, given below as a factual account of the work done, which included a small improvement in design.

Since the resistance units would be used as tension indicators to link periodic soil samplings, fabric units sensitive to low tensions were not appropriate. Gypsum units whose change of resistance reliably indicated cessation of downward drainage were made to a simple design and method of production developed in the course of earlier studies [13]. To distinguish them from the rectangular 'Bouyoucos Block' they are referred to as 'Moisture Gauges', after Croney, Coleman, and Currer [10].

For laboratory manufacture the simple electrode system of the Bouyoucos pattern gypsum block is both cheap and convenient, but the casting of such electrodes into a flat rectangular plate has two disadvantages. Firstly there is a considerable external field in wet soil, and secondly, since drilling equipment must make bores of circular section, flat blocks, when placed deep, must be packed with disturbed soil. Both difficulties can readily be minimized by casting the electrodes into a gypsum cylinder. The electrodes were made by straightening and solder-dipping the bared ends of plastic-covered twin lamp-cord. They were then threaded through spacing bars cast from gypsum and drilled through a metal template (Fig. 3). The electrode assemblies

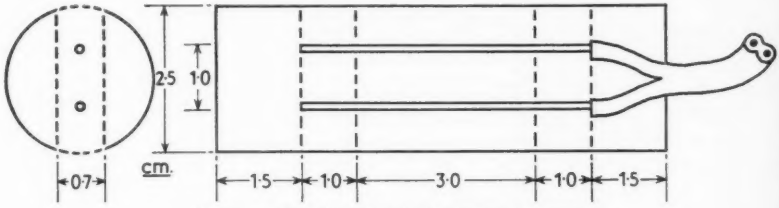

FIG. 3. Details of Soil Moisture Gauges

were then hung into cylindrical moulds. An electrical vibrator was employed during casting. Curing, to secure a uniform and stable hydration of the gypsum, is most important. All the newly cast gauges were left under water for one to two weeks until their resistances at the same temperature became steady. In a check on the external electrical field at saturation, these gauges were compared with Bouyoucos-pattern gypsum blocks of U.S.A. commercial origin. After immersion in water overnight the units were dried externally with blotting paper. Their resistances were measured first in air and again after reimmersion in the water which had become saturated with calcium sulphate. The log-resistance values fell 25·2 per cent. for Bouyoucos Blocks but only 1·3 per cent. for the gauges described here. The standardization of electrode spacing gave a product of very uniform performance, and when recovered from the field after five years, the deterioration was found to be negligible.

Placement in the field using a separate drilling for each moisture gauge was by the methods already described [6]. The resistances were measured initially by a specially adapted Evershed and Vignole 'meg insulation tester' and later by the more convenient and sensitive Baird & Tatlock ohmmeter. Both are robust portable hand-driven alternating-current ohmmeters with scales reading in log-ohms.

MAIZE

GROUNDNUTS

MAIZE

GROUNDNUTS

PLATE 1. Root systems of maize (Kenya Yellow) and of groundnuts (Natal Common) at harvest. The pits are 6ft. deep

FERTILIZER EXPERIMENTS IN CYPRUS. III. FRUIT TREES AND VINES

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Summary

1. In four experiments with vines marked responses to nitrogen and, to a lesser extent, to phosphorus fertilizer, have been obtained. The effect of potassium fertilizer was negligible.

2. No effect of fertilizers on the density of the grape must was obtained except in one experiment in which nitrogen caused a decrease and potassium an increase.

3. In two experiments, one with oval oranges and one with grapefruit, marked responses have been obtained to nitrogen and phosphorus when added together, but not separately. Phosphorus also had a marked beneficial effect on fruit quality. Potassium had no effect on either yield or quality.

4. In one experiment the yield of olives was significantly increased by ammonium sulphate and to a much smaller extent by animal manure, but superphosphate had no effect.

5. Figures are given for the nitrogen, phosphorus, and potassium content of the leaves in all the experiments and their significance is discussed.

In this paper are given the results of experiments with vines, citrus, and olive trees. Experiments with perennial crops should continue for a number of years, preferably ten or more. This proved impossible with the experiments described here, which had to be carried out in privately owned vineyards or orchards, where conditions made it impossible to carry them on for more than a few years.

The need for guard rows increases the size of plots, which affects the accuracy of the experiments. Most vineyards are planted on fairly steep slopes in hilly areas where soil variability imposes severe limitations on the layout of experiments. A further difficulty, peculiar to deciduous fruit trees in Cyprus, is that they are mostly grown on very small bench terraces in the hills; under such conditions even a small experiment consisting of not more than three or four treatments may be so influenced by soil variability as to be valueless. For this reason no experiments have been attempted with apple, pear, or cherry trees.

In spite of these difficulties useful results have been obtained with vines, citrus, and olives, but numerous questions require further investigation.

Vines

Four experiments have been carried out with vines; particulars are given below:

Experiment

1. Raw clay loam derived from gabbro. At Saitta in southern range, 2,200 ft. above sea-level. Moderate slope. Variety Malaga. $2 \times 2 \times 2$ NPK factorial design. Two replications.
2. Alluvial calcareous clay; slightly impeded drainage and alkaline subsoil. At Kondea in central plain about 100 ft. above sea-level.

[Empire Journ. of Exper. Agric., Vol. XXVI, No. 103, 1958.]

Irrigated once annually with slightly brackish water. Variety Sultana. $3 \times 2 \times 2$ NPK factorial design. Three replications.

3. Shallow raw calcareous soil. At Monagri in southern range about 1,500 ft. above sea-level. Strong slope. Variety Cyprus Black. $3 \times 2 \times 2$ NPK factorial design. Two replications.
4. Moderately deep calcareous colluvial clay. At Vasa about 1,500 ft. above sea-level. Moderate variable slope. Variety Malaga. $3 \times 3 \times 2$ factorial design. Two replications with partial confounding.

The planting distances were 6×6 or 7×7 ft. and the size of plots varied from six to nine vines. In experiments 1–3 a single guard row was used. The fertilizer was applied in February in a band 2 ft. wide and 1 ft. from and around the main stem, and hoed to a depth of 6 in. It is possible that some of the nutrients added were taken up by the plants in the adjacent guard rows, which would make the effective dressings lower than those given in Table 1. In experiment 4 a double guard row was used and each fertilizer dressing was applied not only to the experimental plot of six plants but also to the guard contiguous to it. The plots were rather small, but this was dictated by the small area available for each experiment, which also restricted the number of replications to two or three.

The results are summarized in Table 1. In experiments 2 and 4 the effect of treatment in the first year was negligible. In experiment 3, the effect of treatments was negligible for the first two years in spite of the marked improvement, even in the first year, in the appearance of the leaves in the plots receiving nitrogen. It may be significant that soil conditions in this experiment were the poorest of the lot, the soil being very shallow and its water-storing capacity correspondingly low. Only in experiment 1 was a marked and significant response to treatments obtained in the first year. Experiments 1–3 continued for one year after that in which the treatments first had an appreciable effect. Since substantially the same results were obtained in the two years, only the means for this period are given. Experiment 4 had to be unavoidably discontinued after the second year, so that the results of only that year can be given.

Effects on yield. The results of all four experiments show clearly the marked beneficial effect of nitrogen. It is not possible with such a small number of experiments to determine the optimum dressing of nitrogen fertilizer, but it seems that it should be well over 2 cwt. ammonium sulphate per acre.

The effect of superphosphate was significant in experiments 3 and 4. In experiment 2, although the apparent effect was not itself significant, the enhancement of the effect of nitrogen by phosphorus was significant. As in the previous papers, the actual enhancement of the effect is given, and not the NP interaction which is one-half this figure (cf. p. 284, Vol. 25). This enhancement was also significant in experiment 4.

The effect of phosphorus is of interest in view of the fact that the topsoil is practically completely dry after May, so that, from then until harvest time, the plant is unable to obtain any phosphorus; it can do so

TABLE 1. *Effect of Nitrogen, Phosphorus, and Potassium on the Yield of Grapes (cwt. fresh grapes per acre)*

Experiment	*Mean yield without N and P*	*Response to nitrogen*							*Response to phosphorus*							*N/P interaction (enhancement of the response to N by P)*	*Response to potassium*		
		Unit N dressing (cwt. N/acre)	*Without phosphorus*			*In presence of phosphorus*			*Unit P dressing (cwt. P_2O_5/acre)*	*Without nitrogen*			*In presence of phosphorus*				*Mean yield without K*	*Dressing of K (cwt. K_2O/acre)*	*Mean response to K*
			Single dressing	*Increase to double dressing*	*Double dressing*	*Single dressing*	*Increase to double dressing*	*Double dressing*		*Single dressing*	*Increase to double dressing*	*Double dressing*	*Single dressing*	*Increase to double dressing*	*Double dressing*				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	54·5	1·05	7·1	..	7·1	23·3*	..	23·3*	1·1	−9·9	..	−9·9	8·3	..	8·3	16·2	55·0	1·12	5·2
2	73·8	0·45	1·7	1·0	2·7	29·1*	−3·8	25·3*	0·45	−11·3	..	−11·3	11·3	..	11·3	22·6*	79·0	0·75	−2·1
3	21·5	0·45	9·0*	4·4	13·4*	2·9	12·0*	14·9*	0·45	8·0	..	8·0*	9·5*	..	9·5*	1·5	32·7	0·45	−1·0
4	141·4	0·45	6·4	−10·7	−4·3	23·1	26·1	49·2*	0·45	−14·3	−1·8	−16·1	33·2	4·2	37·4*	53·5*	148·5	0·45	1·9

* Significant response at P = 0·05 level.

only during the period from the middle of March, when new growth begins, to the middle of May. The time of picking varies from the middle of July for Sultana in the plains (experiment 2) to September for Cyprus Black and Malaga in the hills (experiments 1, 3, and 4).

Most probably all vineyard soils in Cyprus are very deficient in phosphorus, since it is only during the last decade that the practice of applying fertilizer to vines has begun. No residual effect of phosphorus fertilizer from previous dressings was therefore to be expected when these experiments were laid down. Under these conditions bigger responses to phosphorus were expected. For instance, a marked response to superphosphate was obtained in an experiment with potatoes carried out on a soil identical with that in experiment 1. (Experiment 10 in Table 2 in the first paper of this series [1].) The relatively small responses of vines to phosphorus may be due to the difficulty experienced by the plant in obtaining this nutrient from the top-soil or to the relatively smaller requirements of vines, as well as of other perennial crops, for this nutrient as compared with annual arable crops. It would be of interest to test the effect of deep placement of phosphorus fertilizer on vines.

As with all other crops on which experiments have been carried out in Cyprus, the effect of potassium on the yield of grapes was negligible in all four experiments.

Effect on quality. No thorough assessment was made of the effect of fertilizer dressings on the quality of grapes either for wine or table purposes, or on their ability to stand transport and long storage. Tests have been confined to measurements of the density of the must, carried out on samples taken at the time of picking. The results are given in Table 2. Since no interaction reaches significance or is of appreciable magnitude, the main effects only are given. It will be seen that the treatments had a significant effect in experiment 1 only, where nitrogen reduced and potassium raised the density. These effects were significant in both years of the experiment.

TABLE 2. *Effect of Fertilizer Treatments on Density of the Must (degrees Beaumé)*

Experiment	*Mean density*	*Mean response to*						
		N_1	*Increase,* N_1 *to* N_2	N_2	P_1	*Increase,* P_1 *to* P_2	P_2	K
1	13·2	−1·05†	..	−1·05†	0·35	..	−0·35	0·85†
2	13·65	0·1	0·15	0·25	0·0	..	0·0	0·45
3	12·15	−0·4	0·15	−0·25	0·1	..	0·1	0·40
4	14·55	0·45	−0·05	0·40	0·35	0·40	0·05	0·30

† Significant response at P = 0·01 level.

While the effect of nitrogen might be expected, that of potassium is rather surprising, since this is the only case in all the recorded fertilizer experiments carried out in Cyprus where potassium had a positive and significant effect. Further work is obviously needed on this particular

soil type to determine whether a deficiency exists. Potatoes did not respond to potassium in an experiment on an identical soil, but the effect on the starch content was not tested in this or other experiments with potatoes.

Leaf analysis. A systematic sampling and analysis, over many years, is necessary before a limiting value can be established under any given set of conditions. However, where the nutrient supply is well above or below such limiting value, leaf analysis can detect sufficiency or deficiency even if this value has not been accurately determined. The figures given in this paper do not aim at establishing a limiting value but rather to indicate the content of nutrients to be expected.

Samples were collected by picking the fifth or sixth leaf from the tip of a shoot. For samples selected in May or June these were the youngest fully mature leaves. Leaves were taken from all sides of the plant. The entire leaf was analysed.

A summary of the results is shown in Table 3:

TABLE 3. *Mean Nitrogen, Phosphorus, and Potassium Contents of Vine Leaves (per cent. of dry matter)*

Treatment	*Nitrogen*			*Phosphorus*			*Potassium*	
	N_0	N_1	N_2	P_0	P_1	P_2	K_0	K_1
Experiment 1								
2nd year May 1950 .	3·56	3·47	..	0·36	0·38	..	1·10	1·25
Experiment 2								
2nd year May 1950 .	3·24	n.d.	3·42	0·43	0·42	..	1·38	1·40
3rd year June 1951 .	2·46	2·56	2·54	0·185	0·190	..	n.d.	n.d.
Experiment 3								
2nd year May 1950 .	2·51	n.d.	2·86	0·30	0·31	..	1·24	1·39
3rd year June 1951 . .	2·36	2·50	2·85	0·211	0·225	..	n.d.	n.d.
3rd year August 1951 .	2·20	2·24	2·26	0·161	0·159	..	n.d.	n.d.
4th year August 1952 .	2·02	2·14	2·25	0·133	0·141	..	n.d.	n.d.
Experiment 4								
2nd year July 1954 .	2·90	2·85	2·92	0·161	0·175	0·170	n.d.	n.d.

n.d. = not determined.

With the exception of the nitrogen content in experiment 3, the effect of treatments on the nitrogen, phosphorus, and potassium contents of the leaves was very small. Even in experiment 3 the differences between treatments appear to diminish considerably as the season advances. It is worthy of note that the nitrogen content of the leaves was smallest and the effect of nitrogen, on a percentage basis, largest in this experiment.

The nitrogen content, and even more that of phosphorus, fell rapidly as the season advanced, but it was surprisingly high in May, when the leaves were little more than 2 months old. The nitrogen and phosphorus contents during this month were probably falling rapidly and it does not seem advisable to take samples for diagnostic purposes at this time, since a difference of 2–3 weeks may make a considerable difference in the analytical results. Although no limiting values can be determined with any accuracy from so few results, it appears that for 3-months-old leaves nitrogen contents of well over 2·50 per cent. and phosphorus over 0·20 per cent. denote no deficiency.

The few results for potassium refer only to samples taken in May and lower figures would probably have been obtained in June. In view of the persistent failure of potassium fertilizers to raise yields these results are almost certainly well above the limiting value, which for June sample is probably less than 1 per cent.

Citrus

Two experiments have been carried out, one with oval oranges and the other with grapefruit, in an orchard near Limassol on the south coast. The soil is a heavy calcareous terra rossa. Planting distance was 15×15 ft. This is too close, and although the trees were barely 15 years old, their branches touched. Each plot consisted of a row of three trees and with a single guard row. The fertilizers employed were ammonium sulphate, 16 per cent. superphosphate, and potassium sulphate. They were applied in February of each year, under the canopy of each tree, and hoed-in to the depth of 5–6 in. As the guard rows received no fertilizer dressings it is probable that they took up some of the added nutrients, so that the effective dressings per plot must have been rather less than those actually given. A $3 \times 2 \times 2$ NPK factorial design was adopted, with two replications in each experiment. The experiment lasted four years, in the first of which there was no yield response to treatments. The fruit was picked in December or January. The results are given in Table 4.

TABLE 4. *Effect of Inorganic Fertilizers on the Yield of Citrus*

	No. of fruits per tree					
	Oranges			*Grapefruit*		
	1950	*1951*	*1952*	*1950*	*1951*	*1952*
Mean yield without N and P	517	198	82	465	180	275
Response to nitrogen (unit dressing 1·2 lb. N per tree)						
Without phosphorus						
Single dressing	15	60	70	−155†	−95	−65
Increase to double dressing	−97*	−10	−29	6	8	−12
Double dressing	−82*	50	41	−149†	−87	−77*
In presence of phosphorus						
Single dressing	74*	150*	178†	81*	230†	158†
Increase to double dressing	−31	−1	171†	64*	48	92*
Double dressing	43	149*	349‡	145†	278†	250‡
Response to phosphorus (unit dressing 0·9 lb. P_2O_5 per tree)						
Without nitrogen	50	24	−25	−13	60	−53
In presence of nitrogen (double dressing)	175†	23*	283‡	281†	425‡	274‡
Enhancement of the response to N (double dressing) by P	125	99	308‡	294†	365‡	327‡
Response to potassium (Mean for presence and absence of N and P)	6	−77	24	5	16	5

* Significant response at P = 0·05 level. † Significant response at P = 0·01 level. ‡ Significant response at P = 0·001 level.

Effects on yield. The rapid reduction in yield after 1950 in the plots receiving no nitrogen and phosphorus is probably to be explained by the absence of regular dressings during the war and early post-war years as a result of which the soil was becoming impoverished at the time this experiment began. The marked response to nitrogen and phosphorus together is noteworthy. Where either was omitted the response was insignificant or even negative. It is of interest to compare the marked response to a dressing including phosphorus in these experiments with the relatively small responses obtained with vines. Although the difference may be due to different soil conditions or to the different requirements of the two crops, the fact that citrus is irrigated and the top-soil, to which the added phosphorus is confined, is kept moist throughout the summer must be an important contributing factor. Here also, potassium had no effect.

Measurements of the actual weights of the 1950 and 1951 crops led to much the same conclusions as those obtained from the number of fruits. It was not possible to weigh the 1952 crop.

Effects on quality. The meaning of the term quality varies with the crop. In the case of oranges and grapefruits good quality means large size, smooth skin, good colour, and high juice content with a high total-soluble-solid and low acid percentage. A high juice content is normally correlated with thickness of rind which in turn shows a high correlation with smoothness of skin. Early maturity is also of importance in many areas. All these characters were markedly affected by fertilizer treatments.

In November 1952, the last year of the experiment, the following determinations were carried out on samples taken from all plots of the orange experiment: percentage of juice by weight, and total-soluble-solids and acid content (calculated as citric acid) of the juice. Estimates of roughness, thickness of skin, and greenness were also made. In January 1953 further samples were taken and determinations of the total-soluble-solids and acid content of the juice made. The results are given in Table 5. Treatments had little effect on the total solids but a marked one on the acid content and, consequently, on the total-solids : acid ratio customarily employed as an index of maturity.

These results show that the application of superphosphate had a marked and significant beneficial effect on both the juice content and the total-solids : acid ratio. The effect of nitrogen in the absence of phosphorus was negative, but not significantly so. The effect of potassium was negligible.

The increase in the juice content of fruits from the P plots is probably due to the considerably thinner rind as compared with those receiving nitrogen only. A comparison of the samples taken in November also showed that the fruits from the plots receiving only nitrogen had a much rougher skin and their colour was much greener than those from all other plots, and particularly those receiving only superphosphate.

The size of oranges was increased by nitrogen and reduced by phosphorus, both effects being significant. The effect of nitrogen was predominantly confined to the plots not receiving phosphorus. The increased size of the fruit was mainly due to an increase in the thickness of rind and was, therefore, an undesirable effect. When the crop is small

TABLE 5. *Effect of Fertilizer Treatments on the Total Juice Content of Oranges and its Total-Solids : Acid Ratio*

	November 1952			*January 1953*
	Percentage juice by weight	*Mean weight of fruit: oz.*	*Ratio Total solids: acid*	*Total solids: acid*
Without N and P . . .	28·5	7·8	4·95	6·10
Effect of N (double dressing):				
Without P	−3·7	1·34†	−0·10	−0·65
In presence of P . . .	1·6	0·18	0·52	0·25
Effect of P:				
Without N	1·6	0·38	0·03	0·73
In presence of N (double dressing)	6·9*	−0·78*	0·65*	1·13†
Enhancement of effect of P by N	5·3	−1·16*	0·62	0·40
Mean effect of K . . .	0·66	0·11	0·08	−0·10

* Significant effect at P =0·05 level. † Significant effect at P =0·01 level.

the fruit is likely to be large, with a rough and thick skin. In this case, the effect of nitrogen cannot be the result of the small crop only, since the yields were roughly the same as in the plots receiving superphosphate only or in the control plots. However, the large and significant negative interaction of the two fertilizers must be the result of the marked increase in yield where both nutrients were added. In 1950 and 1951 the size of oranges as determined from measurements of number and total weight was not significantly affected by treatments. As already mentioned, the 1952 crop was not weighed.

Similar results for juice content were obtained with grapefruit, but the effects of treatments on the total-solids : acid ratio were very small. As the samples from plots receiving the same treatment were pooled, no tests of significance were possible in this case.

It is regrettable that the effects of fertilizer treatments on the yield and quality of citrus, and in particular that of potassium, could not be followed up for a longer period, since there was some indication that potassium had an adverse effect on fruit quality.

Leaf analysis. The youngest fully developed leaves on the current year's branches have been taken in the spring for analysis. In 1950 they were taken from vegetative branches, but in 1951 and 1952 from fruit-bearing branches. The results are shown in Table 6. Samples from plots receiving the same treatment have been pooled, so that no tests of significance were possible.

Treatments appear to have had an effect both on the nitrogen and the phosphorus content of the leaves. There is an apparent contrast between the behaviour of nitrogen, the average content of which did not change much from May to November or December, and that of phosphorus, which showed a sharp drop during the same period. Actually, the nitrogen content of grapefruit leaves taken from the N_2P plots fell sharply

TABLE 6. *Mean Effects of Fertilizer Treatments on the Nutrient Content of Leaves (per cent. of dry matter)*

	Nitrogen		*Phosphorus*	
	N_0	N_2	P_0	P_1
Oranges:				
May 1950	2·14	2·55	0·141	0·146
May 1951	2·08	2·18	0·128	0·161
November 1951	1·81	2·23	0·096	0·092
July 1952	1·50	1·93	0·080	0·104
Grapefruit:				
May 1950	1·68	2·11	n.d.	n.d.
May 1951	1·69	2·12	0·102	0·131
December 1951	1·45	2·37	0·058	0·078
July 1952	1·58	1·95	0·063	0·089

n.d. = not determined.

from 2·06 to 1·55 per cent., while that from the N_2-only plots rose sharply from 2·16 to 3·20 per cent. during the same period, the average figure for all N_2 plots remaining roughly the same. No similar difference between the N_2 and the N_2P plots was observed in the orange experiment. The difference is probably due to the fact that whereas the production of grapefruits in the N_2P plots was nearly 200 per cent. higher than in the N_2-only plots, the corresponding increase in oranges was less than 50 per cent.

The fairly large effect of dressings of superphosphate on the phosphorus content of the leaves of citrus should be compared with the negligible effect obtained with vines, the differences being probably due to the fact that citrus is irrigated and thus able to take up phosphorus from the top-soil throughout the period of growth. These results are consistent with the rather small response of vines to superphosphate, as compared with citrus.

Although these results do not enable one to determine a limiting value with any certainty, it appears that the limit for nitrogen lies around 2 per cent. and for phosphorus 0·10 per cent. and that values of 1·50 and 0·06 per cent. respectively denote a marked deficiency even for 8–10-months-old leaves.

No potassium determinations were carried out except on orange leaves in May 1950. For these the average results were 2·13 per cent. for the K_0 plots and 2·07 per cent. for the K_1 plots. Such levels must be considered as indicative of abundant supplies of available soil potassium.

It is of interest to compare the results of this experiment with those of another with oval oranges which has been in progress for five years in Famagusta on a red loamy sand underlain at a depth of 2–3 ft. with red clay. Possibly because of the much greater depth of soil and, consequently, of the greater reserves of nutrients, no response to any treatments has been obtained up to the present. In agreement with these results, it was found in August 1956 that the nitrogen content of the dry matter of the leaves was well above 2·0 per cent., the phosphorus content 0·1 per

cent. and the potassium content 1·5 per cent. in almost all plots. Such levels render unlikely any response to fertilizers.

Olives

The main variety of olive grown in Cyprus is a local one, high in oil content and grown mainly for the production of oil. It is generally unirrigated and thrives best in deep calcareous soils especially in the coastal areas where rainfall is rather higher than in the central plain. Very few regularly planted olive groves exist and most of the trees are grown at irregular distances in association with annual crops. This renders it very difficult to carry out any experiments with this crop.

A second difficulty is the highly irregular bearing of olive trees. Since fluctuations of yield in individual trees do not as a rule coincide, the results of single years may be meaningless. It is therefore essential that experiments with olives should last for an even longer period than with other trees so that the results may be averaged over a number of years.

Two experiments started in the central plain had to be abandoned after three years during which they gave highly erratic results. A third experiment, near Kyrenia on the north coast under an average rainfall of 22 in., proved much more satisfactory and it has been possible to keep it going for five years. The soil is a deep alluvial calcareous clay. This experiment, which is still in progress, was laid down in a small grove with trees about 15 years old and planted at distances of 32 × 32 ft. There was room only for a 2 × 2 × 2 NPK experiment with two replications, each plot consisting of three trees. No guard rows were possible. It was hoped that the fairly large planting distance would reduce interference from adjacent rows and this has proved to be the case, at least to the extent of not obscuring the effect of some treatments. The results are shown in Table 7.

TABLE 7. *Effect of Nitrogen, Phosphorus, and Animal Manure on the Yield of Olives*

	lb. fresh fruit per tree: mean of five years, 1952–6
Yield of control plots	34·6
Mean effect of N (1·1 lb. per tree per year)	+12·4‡
Mean effect of P (0·45 lb. P_2O_5 per tree per year)	+1·4
Mean effect of goat manure (112 lb. per tree per year)	+3·7
Enhancement of effect of N	
by P	+6·7
by manure	−2·8
Enhancement of effect of P	
by manure	+5·7

‡ Standard error per plot mean ±4·2 (10·6 %).

Nitrogen as ammonium sulphate and phosphorus as 16 per cent. superphosphate were applied in February and animal manure in November. The effect of nitrogen has proved very consistent and reached significance almost every year, whereas the mean effect of animal manure did not reach significance. No two-factor interaction reached significance, but the apparent effects of phosphorus on the response to nitrogen, and

of manure on that to phosphorus were positive and appreciable. It is questionable, however, whether the latter is real since one would expect a negative interaction between goat manure and phosphorus.

Since this grove is not irrigated and the top-soil dries out in the summer the failure of phosphoric acid to have an effect may be due to the inability of the roots to take it up. It is more likely, however, to be due to the low phosphoric acid requirements of olive trees.

The relatively low, and non-significant, effect of animal manure demonstrates the low availability of the nitrogen contained in it. No regular analyses of this manure were carried out but the few results give a nitrogen content of about 1 per cent. in the dry matter. As already discussed in the first paper of this series [1] the methods of manure conservation in Cyprus are crude and wasteful and the resultant manure cannot compare with the farmyard manure of western Europe.

Annual determinations of the oil content of olives failed to reveal any differences between treatments, but the results were erratic and inconclusive, probably because of the difficulties in obtaining representative samples.

The results of this experiment do not necessarily apply to other localities where lower rainfall may result in lower yields and reduce the need for nitrogen.

Leaf analysis. Leaf analyses were carried out on samples taken from all plots in July 1956. Only leaves in the fifth or sixth position from the tip of the current year's branches were selected. The results are given in Table 8.

TABLE 8. *Nitrogen, Phosphorus, and Potassium Content of Olive Leaves (per cent. of dry matter)*

Nitrogen		*Phosphorus*		*Potassium*	
Mean of		Mean of		Mean of	
N_0M_0	1·19	P_0M_0	0·112	M_0	1·10
N_0M_1	1·42	P_0M_1	0·107	M_1	1·11
N_1M_0	1·59	P_1M_0	0·109	..	
N_1M_1	1·56	P_1M_1	0·113	..	

It will be seen that the nitrogen content was apparently raised by dressings of ammonium sulphate and, to a lesser extent, of manure, but the results were not significant. These results suggest that a nitrogen content of less than 1·50 per cent. was an indication of deficiency, but this figure may not be applicable under drier conditions. The level of phosphorus was probably adequate, since it was above the limit suggested for citrus, the nutrient requirements of which are much higher than for olives. Similarly the potassium content was almost certainly satisfactory. Fertilizer treatments had little effect on the level of this nutrient in the leaf.

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FERTILIZER REQUIREMENT OF CROPS IN CYPRUS
IV. EFFECT OF DIFFERENT TYPES OF PHOSPHATIC FERTILIZER

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Summary

In two experiments bone meal has been found to be ineffective on potatoes and wheat on calcareous soil of pH8 and its residual effect, tested in one experiment, proved negligible.

In four experiments with wheat and potatoes the average effect of dicalcium phosphate was equal to that of superphosphate. The soil was calcareous in all experiments and its pH exceeded 7.

In seven experiments with potatoes and wheat the average effect of basic slag has been nearly the same as that of superphosphate. Most of the soils were calcareous and the pH. exceeded 7 in all cases. Basic slag was equally as effective on potatoes as on cereals.

In one experiment on calcareous clay loam the residual effect of basic slag was much superior to that of superphosphate.

The results are discussed in the light of work carried out in other countries.

It was shown in the three previous papers of this series [1] that, of all the crops tested, potatoes, cereals, cotton, vines, citrus, and possibly olives, responded to dressings of nitrogen as well as phosphorus fertilizers. The phosphorus fertilizer used in all these experiments was single (16 per cent.) superphosphate. A number of experiments are here described in which superphosphate was compared with other types of phosphorus fertilizers.

In all the experiments with wheat the fertilizer was broadcast. With potatoes, a furrow was opened with the local nail plough, the sets were planted, and the fertilizer applied in the furrows; on returning, the plough covered the fertilizer and opened a new furrow in which no potatoes were planted or fertilizer applied. The third furrow was treated like the first and so on. This method of planting potatoes, which is the usual one in Cyprus, involves some degree of placement of the fertilizer. A month or so after planting, earthing up was carried out and furrows opened between the rows in preparation for irrigating the crop.

Bone Meal

During World-war II bone meal became available as fertilizer in Cyprus. In view of the prevailing shortage of superphosphate the efficiency of this fertilizer was tested. An experiment (two 4×4 Latin squares) was carried out at the experimental farm of the Agricultural Department, Morphou, on alluvial clay loam containing about 10 per cent. calcium carbonate. The results are given in Table 1.

A further experiment with wheat was carried out at the same farm in

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TABLE 1. *Comparison of Bone Meal with Superphosphate Yield (cwt. per acre)*

Treatment (applied to the first crop only)	*First crop: potatoes*	*Second crop: wheat (grain)*
1. No P	59·1	12·5
2. Superphosphate (1·2 cwt. water-soluble P_2O_5 per acre)	67·7	19·2
3. Bone meal (1·3 cwt. total P_2O_5 per acre)	61·2	12·0
4. Bone meal ,, ,,	62·9	12·7
Standard error (15 degrees of freedom)	±2·13	±0·31

A basal dressing of ammonium sulphate (3 cwt./acre) was given to both crops. In treatment 4, but not in treatment 3, allowance was made for the nitrogen content of bone meal.

1945, in which the effect of phosphorus fertilizers with and without nitrogen was tried (randomized blocks) but, as nitrogen had no effect, only the mean yields with and without it are shown in Table 2.

TABLE 2. *Effect of Bone Meal and Superphosphate on the Yield of Wheat (cut grain per acre)*

Treatment	
1. No P	6·0
2. Superphosphate (0·18 cwt. water soluble P_2O_5 per acre)	9·1
3. ,, (0·36 ,, ,,)	9·6
4. Bone meal (0·30 cwt. total P_2O_5 per acre)	6·2
5. ,, (0·60 ,, ,,)	5·9
Standard error (9 degrees of freedom)	±0·66

Although superphosphate had a marked direct effect on the yields in both experiments and its residual effect was considerable in the first experiment, bone meal proved ineffective.

Dicalcium Phosphate and Basic Slag

In recent years a number of experiments on dicalcium phosphate and basic slag were carried out. The former contained 40 per cent. phosphoric acid soluble in neutral ammonium citrate solution. Basic slag, obtained from Belgium (Thomas phosphate), contained 17·1 per cent. citric-acid-soluble phosphoric acid and 15·9 per cent. soluble in neutral ammonium citrate solution. Solubility in neutral ammonium citrate is not a usual test for basic slag, but in view of the fact that in certain countries this is an official method of determining 'available' phosphoric acid in other fertilizers, it was thought desirable to apply it to basic slag also.

The results of two experiments (randomized blocks) with superphosphate and dicalcium phosphate are given in Table 3.

The effect of each fertilizer was significant in both experiments. The maximum yield with superphosphate was reached at a lower level of application than with dicalcium phosphate, but the difference was not significant. In general these results do not allow of any conclusions as to a difference in the merits of the two fertilizers. In other experiments

on potatoes superphosphate was compared with basic slag and dicalcium phosphate (3×3 factorial with dummy treatments). The results are given in Table 4.

TABLE 3. *Effect of Superphosphate and Dicalcium Phosphate on the Yield of Potatoes and Wheat (cwt. per acre)*

Treatment	*Experiment I Stony rendzina clay loam. Onisha. Potatoes*	*Experiment I Calcareous alluvial clay loam. Morphou. Wheat (grain)*
No P	52·9	14·4
Triple (48 per cent.) superphosphate		
0·3 cwt. water-soluble P_2O_5	86·6	18·0
0·6 ,,	109·0	16·2
0·9 ,,	99·6	17·1
Dicalcium phosphate		
0·3 cwt. citrate soluble P_2O_5	80·5	16·2
0·6 ,,	96·2	16·8
0·9 ,,	104·6	17·7
1·2 ,,	113·1	17·9
Standard errors (21 degrees of freedom)	±5·80	±0·83

(Basal dressing: 3 cwt. ammoniun sulphate per acre)

TABLE 4. *Effect of Superphosphate, Dicalcium phosphate, and Basic Slag on the Yield of Potatoes (cwt. per acre)*

Fertilizer	P_2O_5 *cwt. per acre*	*Experiment I Calcareous alluvial loam. Avlona*	*Experiment II Slightly calcareous terra rossa clay. Argaki*
Control	nil	77·2	208·9
Basic slag	0·36	100·0	225·0
,,	0·72	129·8	252·0
Dicalcium phosphate	0·36	112·5	258·0
,,	0·72	123·8	246·0
Superphosphate (16 %)	0·36	99·0	258·0
,,	0·72	132·0	273·0
Standard errors, control		±7·2	±11·6
Other figures (16 degrees of freedom)		±12·5	±20·0

(Basal dressing: 4·5 cwt. ammonium sulphate per acre)

In the first experiment the effect of all three fertilizers was the same within the limits of experimental error. In the second superphosphate proved superior to dicalcium phosphate and especially to basic slag, the response to which does not reach significance. However, even in this experiment the differences in the responses to the three fertilizers are well below the level of significance.

Further comparison between superphosphate and basic slag was made in a series of five experiments, three with potatoes and two with unirrigated wheat (3×3 factorial with dummy treatments). The results are given in Table 5.

With the exception of the first experiment with potatoes the effect of

basic slag equalled that of superphosphate within the limits of experimental error. It must be concluded that under the soil conditions of Cyprus dicalcium phosphate and basic slag generally have considerable effect on the yield of these crops, approaching that of superphosphate.

TABLE 5. *Effect of Superphosphate and Basic Slag on the Yield of Wheat and Potatoes (cwt. of grain or tubers per acre)*

Crop, soil, and locality	*Control*	*Basic slag*		*Superphosphate*		*Standard errors*		*Degrees of freedom*
						Control	*Other figures*	
POTATOES		0·36 cwt. P_2O_5	0·72 cwt. P_2O_5	0·36 cwt. P_2O_5	0·72 cwt. P_2O_5			
1. Terra rossa clay, lime-free. Avgorou	100·0	100·2	100·4	106·7	131·3	4·16	5·87	21
2. Terra rossa clay, lime-free. Frenaros	35·0	79·7	85·4	80·7	92·2	3·42	4·82	21
3. Calcareous alluvial clay loam. Morphou	133·0	160·7	163·9	163·3	168·2	6·16	8·70	16
WHEAT		0·18 cwt. P_2O_5	0·36 cwt. P_2O_5	0·18 cwt. P_2O_5	0·36 cwt. P_2O_5			
1. Calcareous alluvial clay. Tricomo	16·9	19·4	20·1	18·8	21·2	0·47	0·67	26
2. Shallow calcareous reddish-brown clay. Akradhes	19·6	22·1	23·5	22·2	22·7	0·76	1·07	26

A basal dressing of ammonium sulphate was given at the rate of 0·9 cwt. N per acre for potatoes and 0·45 cwt. for wheat.

The residual effect of superphosphate and basic slag was investigated in one experiment (No. 3 with potatoes, Table 5). The results are shown in Table 6.

TABLE 6. *Residual Effect of Superphosphate and Basic Slag. Yield of Potatoes or Wheat Grain (cwt. per acre)*

Treatment (applied to first crop only)	*Crop*				
	1st potatoes spring 1954	*2nd potatoes autumn 1954*	*3rd wheat 1955*	*4th potatoes autumn 1955*	*5th wheat 1956*
Control	133·0	66·8	4·2	53·5	5·3
Basic slag 0·36 cwt. P_2O_5	160·7	90·0	7·5	60·0	7·6
,, 0·72 ,,	163·9	109·5	8·8	72·0	9·7
Superphosphate 0·36 ,,	163·3	81·8	5·1	61·5	5·2
,, 0·72 ,,	168·2	78·8	5·6	56·7	5·2
Standard errors control	±6·16	4·41	0·51	*	0·38
,, others	±8·70	6·23	0·73	*	0·54

A basal dressing of 0·9 cwt. N for potatoes and 0·45 cwt. N for wheat was given to each crop.

* Results for this crop have been corrected for plant number and no single standard error can be given. The response to the double dressing of basic slag was significant at the P = 0·05 level.

The residual effect of basic slag is thus seen to have been much superior to that of superphosphate in this particular soil which is representative of large areas as regards pH and calcium carbonate content.

Discussion

The results of these experiments indicate that bone meal is not satisfactory as a fertilizer under Cyprus conditions. Presumably, the same would apply to rock phosphate. Edwards [2] has reported that, in experiments with brassicas and grass, rock phosphate was about half as effective as superphosphate on alkaline soils of moderate calcium carbonate content but that it was almost useless with potatoes even in acid soils. It is obviously desirable that further experiments should be carried out in Cyprus, with rock phosphate, on calcareous alkaline soils, particularly to test its residual effect, but in view of its low direct effect and the poor response given by potatoes, in Edwards' experiments, it is unlikely that this fertilizer can profitably replace superphosphate under Cyprus conditions.

The position is different with basic slag and dicalcium phosphate both of which have been shown here to have a direct effect comparable to superphosphate and the former to have a residual effect markedly superior to superphosphate. The particular site on which the experiment in Table 6 was carried out is known to have received no phosphatic dressings or manure for at least twenty-five years and it has almost certainly never received any other chemical fertilizers. It is possible that different results will be obtained on soils receiving regular dressings of superphosphate, since in that case the phosphate-fixing capacity of the soil will eventually be saturated and the residual effect of superphosphate may be greater and last longer on such soils.

Certain observations appear to bear this out. The long-term fertilizer experiments described by Littlejohn [3] were abandoned a few years ago, but one replication from each experiment was preserved in order to determine the residual effect of long-continued application of superphosphate. Each plot was divided into four subplots and the following treatments given: Nil, N, P, NP. Wheat was grown for two years but heavy weed infestation caused great variation in the yield of grain. It was noted, however, that where no phosphorus had been given previously, both nitrogen and phosphorus were needed to improve vegetative growth. Where previous dressings of superphosphate had been given, nitrogen alone sufficed to improve vegetative growth. This was true whether the previous annual dressings of 16 per cent. superphosphate had been 1·5, 3, or 6 cwt. per acre. Later, potatoes were grown and the results agreed well with those based on observations of the vegetative growth of wheat. These observation plots still continue and it is obvious that dressings as small as 1·5 cwt. superphosphate per acre, applied annually for twenty years, have marked residual effect lasting for at least four years, in contrast to the results recorded in Table 6. The site of Littlejohn's experiments is adjacent to that of the experiment in Table 6, and soil conditions are identical.

The results reported in this paper appear to contradict recent work carried out in other countries. For instance, Speer *et al.* [4] report that on Houston black clay (40 per cent. calcium carbonate, pH 8) using P 32 as radioactive tracer, the phosphorus uptake by plants was high

with superphosphate, double superphosphate, and other sources of water-soluble phosphoric acid but that dicalcium and fused tricalcium phosphate were useless. Their experiments extended only for 45 days and it would be of interest to know whether the same results would have been obtained over the entire growing period.

Bennett *et al.* [5] reported on the results of experiments with twenty phosphorus fertilizers on Houston black clay. They concluded that 20 per cent. superphosphate was much superior to dicalcium phosphate which on the whole they found to be only slightly superior to tricalcium phosphate. However, of the five crops on which the experiment was carried out, superphosphate had a significant effect in three and dicalcium phosphate in one and in only one experiment was the difference between the effects of superphosphate and dicalcium phosphate significant.

Schmehl and Brenes [6] reported that Rhenania-type phosphate containing 25 per cent. citric-soluble phosphoric acid was as effective as superphosphate on calcareous Colorado soils when broadcast but less so when side-dressed. In view of the very rapid fixation of superphosphate indicated by the results given in Table 6, it is possible that, in Cyprus soils also, superphosphate would prove superior to fertilizers with non-water-soluble phosphorus, if side-dressed, at least as regards its direct effect.

In Great Britain the work of Mattingly and Widdowson [7] indicates that dicalcium phosphate was nearly as effective as superphosphate even on calcareous, slightly alkaline soil. Cooke [8] found that the two fertilizers were approximately equivalent even on neutral soils (pH 6·5 or over). It is not clear whether this includes calcareous soils of pH 8 or more, and consequently whether his results can be compared with those obtained in Cyprus.

On neutral (pH 6·5 or over) and less acid (pH 5·6–6·5) soils Cooke found basic slag to be as effective as superphosphate containing one-half to two-thirds as much phosphoric acid. His experiments were carried out with Bessemer basic slag containing 17·5 per cent. total phosphoric acid of 88 per cent. solubility in citric acid and, presumably, similar to Thomas phosphate. The results of the experiments in Cyprus indicate that the direct effect of basic slag approaches that of superphosphate. The average effect of basic slag at the rate of 0·36 cwt. phosphoric acid per acre was 95 per cent. of that of superphosphate applied at the same rate. It is not desirable to work out 'superphosphate equivalents' [8] from the response curves since they are very flat above 0·36 cwt. and consequently the error is very great. It would be of interest to determine the effect of dressings smaller than 0·36 cwt. so as to utilize the steepest portion of the response curve for determining superphosphate equivalents. On the other hand, the greatly superior residual effect of basic slag as compared with superphosphate will, if confirmed by further experiments on slightly alkaline calcareous soils, make the use of this fertilizer an attractive proposition on such soils.

The possibility that part of the effect of basic slag in these experiments is due to its content of trace elements is considered unlikely. Annual

crops in Cyprus have never been observed to show symptoms of trace-element deficiency apart from occasional iron deficiency in irrigated legumes such as haricots. Even on fruit trees zinc deficiency is not very extensive, and the existence of manganese deficiency is doubtful.

In general these results show that fertilizers containing citrate-soluble phosphoric acid have a marked effect, even in alkaline soils, on wheat and potatoes, but further work is needed in order to make an accurate comparison of their effect with that of superphosphate and to determine their residual value.

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BARN-ROT DISEASE OF FLUE-CURED TOBACCO IN SOUTHERN RHODESIA[1]

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Summary

Preliminary experiments were carried out on the effect of factors associated with the curing environment on barn-rot disease development during the colouring period.

The onset of the disease was faster and the subsequent damage greater as the yellowing temperature was increased from 80 to 110° F. and when the relative humidity was raised from 50 to 100 per cent. These factors operated independently though the evidence was insufficient to determine which was the more important.

The more mature the leaf at reaping, the quicker was the onset of the disease. Slightly more damage appeared to occur on immature leaf, as compared with overripe leaf, possibly because it took longer to yellow.

BARN-ROT disease (*Rhizopus arrhizus*, Fischer) of flue-cured tobacco has been very prevalent in recent years. The financial loss depends on how much of the leaf is affected; apart from actual loss of leaf, extra labour and time are required to salvage partially damaged leaf.

A study of some of the factors associated with the curing environment was carried out to determine their influence on barn-rot incidence and development and the results of these preliminary experiments are reported here.

Review of Literature

Hopkins [1, 2, 3] reported that lack of adequate ventilation, high humidity, and restriction of air circulation by too close packing were conditions favourable for development of the disease. The disease could apparently be prevented by improving the ventilation and air circulation in the barn. Hopkins [4] also noted that overripe leaf was highly susceptible.

From observations and experiments Norval [5] noted that damage from barn rot was less in lightly packed barns because in these the colour could be fixed and the leaves dried more quickly than in tightly packed ones, but tying the leaves in fives instead of threes did not increase the amount of barn rot. Since the rot took between 48 and 60 hours to appear, he considered that control might be effected by reaping leaf which would yellow in 48 hours or less and then fixing the colour by a rapid rise in temperature to 140° F., with full ventilation.

Pearse [6], using small curing chambers and relying on the natural occurrence of the disease, reported that the ripest leaves were the first to be attacked and, under the experimental conditions, showed the highest incidence of barn rot. However, he suggested that such leaves

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escaped attack during normal curing because the relative humidity would have been reduced and the temperature raised before they had reached the susceptible stage. With less mature leaves more damage might be expected, as the leaf would have to be maintained longer in high humidity in an attempt to obtain colour. Pearse further recorded that, from growers' reports and his own results, it was evident that leaf rarely exhibited barn-rot symptoms until at least 50 hours from the start of curing.

The effect of different colouring temperatures and humidities does not appear to have been studied previously.

Materials and Methods

Nicotiana tabacum var. Delcrest was used in all trials.

When temperature or humidity was being studied, mature leaf of uniform ripeness, from approximately the same position on the plant, was selected for test. For trials concerning maturity leaf was selected on the basis of degree of ripeness, as evidenced by the colour.

Pure cultures of *Rhizopus arrhizus*, grown on potato-dextrose agar, were used as inoculum; the mycelium was separated from the agar, mixed with distilled water and fragmented in an Ato-mix blender. The butts were dipped in the inoculum and the leaves were suspended from thin flat metal 'needles', approximately $\frac{1}{2}$-in. wide, which pierced the midrib 3 to 4 in. from the butt end. Four leaves, hung close together, constituted one replicate.

All trials were carried out in Gallenkamp Humidity Ovens in which temperature and humidity were controlled, by means of wet- and dry-bulb thermometers, to an accuracy of $\pm 0{\cdot}5^{\circ}$ C.

The completion of the colouring phase of curing was accepted as the end point of the experiments; by this time the leaves had a uniform yellow appearance, but still retained a green tinge in the veins. In trials involving only temperature or humidity the end point for all treatments was approximately the same. When leaf maturity was under test, however, the end point varied, since it required a longer period to yellow immature or green leaf to the same degree as with overripe leaf.

Disease Assessment

It was observed in initial trials that the disease development could be separated into several distinct stages and a category number from 0 to 6 was assigned to each of these, defined as follows:

0 = No symptoms of infection.
1 = Slight water-soaked appearance at the cut end of the butt. Butt not soft.
2 = Butt soft, but not pulpy. Leaf frills alongside butt slightly brown in places. Some mycelium may be present.
3 = Butt soft, tending to pulp—rot extending down to about region where the leaf lamina begins. Leaf frills brown.
4 = Butt pulpy. Rot extending into midrib. May be some browning of leaf lamina, restricted to area nearest butt.

5 = As in 4, but rotting of leaf lamina extending down sides of midrib, and outwards, for about half the length of the leaf.

6 = Butt disintegrating. As for 5, but at least 50 per cent. of the leaf lamina surface affected by the rot.

At the conclusion of a trial the disease incidence on all leaves was assessed. The final disease incidence was expressed as a percentage infection index based on the McKinney Grouping Method [7, 8].

Influence of Colouring Temperature

Several tests were carried out at different times within a range of temperature from 80 to 110° F., at a relative humidity between 90 and 100 per cent. Flue-curing generally begins at temperatures of 85 to 90° F., which are raised at intervals to between 105 and 115° F., when the required colour should have been attained. In the trials, however, the material under test was yellowed at a constant temperature to facilitate interpretation of the results, which are shown in Table 1.

TABLE 1. *Effect of Colouring Temperature on Barn-rot Development*

Temperature (° *F.*)	*Infection index (adj.)* (*Tests 1–4*)	*Level of significance of differences between adjacent means*
80·6	7·3±3·4	
		P < 0·01
93·2	19·5±3·0	
		,, 0·001
95·5	40·2±2·2	
		,, 0·001
98·6	60·4±3·0	
		,, 0·05
102–104	67·0±1·5	
		,, 0·001
110·0	82·0±3·0	

The data in Table 1 showed that the disease incidence increased as the yellowing temperature was raised within the range of 80 to 110° F. During the trials it was observed that the first signs of infection occurred at the higher temperatures; in one instance, 12 hours after the cure had started, symptoms corresponding to stage 1 were observed at temperatures of 98·6 and 104° F., whereas none were visible at lower temperatures. It also appeared that the subsequent development was faster.

When the infection indices were plotted against temperature a typical sigmoid curve was obtained and this was transformed to a straight-line relationship between temperature and disease incidence (adjusted) by the probit transformation. Using the equation of this line, it was possible to predict the extent of damage which could be expected at various yellowing temperatures, provided all other concomitants remained constant; the results are illustrated in Fig. 1.

Influence of Relative Humidity

Brown [9] stated that, during the yellowing phase of curing, sufficient moisture must be kept in the barns to give a reading of 3–4 degrees difference between the wet- and dry-bulb thermometer records. Stinson [10] suggested that this was normally achieved in a barn full of fresh mature leaf. Some farmers, however, supplement the inside humidity

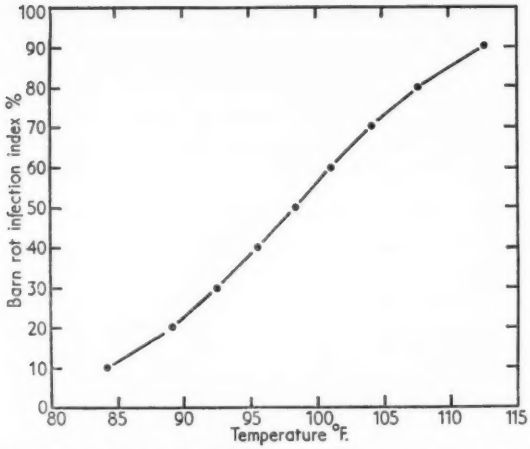

FIG. 1. Relationship between amount of barn-rot damage and yellowing temperature.

by introducing water into the barns, either by placing wet sacks on the floors or flues or by directly applying water to the floors. Stephen (11) advised the use of higher initial colouring temperatures of 100–102° F., together with 100 per cent. relative humidity for the control of barn-spot disease (*Cercospora nicotianae*, Ell., and Ev.).

In view of the variety of humidity conditions which might exist in a barn during yellowing, a range of humidities, varying from 50 to 100 per cent. was tested. The humidities were maintained constant throughout the trials. A constant temperature (dry-bulb reading) of 95° F. was used in the five tests; the results are given in Table 2.

TABLE 2. *Effect of Relative Humidity on Barn-rot Development*

Relative humidity, %	*Infection index (adj.) (Tests 5–9)*	*Level of significance of differences between adjacent means*
100	71·7±2·5	$P < 0.01$
93	58·3±3·5	,, 0·01
87	44·2±3·5	,, 0·001
75	27·1±2·5	,, 0·01
63	17·5±2·5	n.s.
50	11·7±2·5	

The extent of barn-rot development and resultant damage was increased with increase in relative humidity maintained during yellowing. At the lower humidities of 50 and 63 per cent. damage was restricted to the water-soaked appearance near the cut end of the butt; such humidities, however, were not suitable for colouring at temperatures of 95° F. or above, as the leaf still retained a greenish tinge with discoloured patches. At relative humidities of 75 and 87 per cent. the disease was

restricted to the butt which was soft but not pulpy with some rotting of the leaf frills alongside. Only in the case of humidities over 90 per cent. did the disease spread sufficiently to rot parts of the leaf lamina proper.

It was observed that barn-rot symptoms corresponding to stages 2–3 were seen in the 100 per cent. relative humidity treatment as early as 19 hours after the curing had started. At this time the disease development was much less in the slightly lower humidity treatment and entirely absent at humidities of 75 per cent. or less; at these lower humidities the first symptoms did not appear until much later. In addition, it seemed that further development was slower at the lower humidities.

Influence of Temperature and Humidity in Different Combinations

Colouring temperatures of 90 and 104° F., and relative humidities of 83 and 100 per cent. were studied in all combinations in three tests (10–12) which were analysed together; the results are given in Table 3.

TABLE 3. *Effect of Two Colouring Temperatures and Humidities on Barn-rot Development*

Temperature (° *F.*)	*Relative Humidity*		*Mean*
	83 %	*100 %*	
	(±2·63)[a]		(±1·86)[b]
90	11·4	34·2	22·8
104	40·6	64·7	52·6
	(±1·86)[b]		
Mean	26·0	49·4	37·7

Least significant differences for comparisons based on standard errors	P =	0·05	0·01	0·001
	(*a*)	7·5	10·0	13·0
	(*b*)	5·3	7·1	9·2

The results in Table 3 confirmed the previous data, namely that a greater amount of barn-rot damage resulted from the use of relatively high yellowing temperatures and humidities; these factors appeared to exert their effects independently. The evidence was insufficient to determine which was the more important, as the results of the individual trials were not consistent.

Influence of Leaf Maturity at Reaping

Whilst every attempt is made to pick uniformly ripe leaf for curing, it is possible that different barns may be filled with leaf of varying maturity. The more mature the leaf the shorter will be the time required for yellowing.

In the first trial (test 13) leaf was selected to give five classes of ripeness, based mainly on the colour, which ranged from very green for immature leaf to yellowish-green for overripe leaf. In two other trials (tests 14 and 15) the number of classes was reduced to three, namely immature, ripe, and overripe; the material was selected in the field and,

together with a ripe leaf, leaves two positions above and below it were removed, representing the immature and overripe categories respectively.

The leaves were coloured at a temperature of 95° F., with 100 per cent. relative humidity. The incidence of barn rot was assessed on all leaves when those of each 'maturity' attained the required degree of yellowing; the trials were continued until the leaves in the immature category had yellowed; the results are given in Table 4.

TABLE 4. *Effect of Leaf Maturity on Barn-rot Development*

Test 13

Leaf maturity	*Time of assessment*		
	After 41 hrs.	*After 48 hrs.*	*After 66 hrs.*
		(±2·04)[a]	
Very overripe . .	47·5*	62·5	76·7
Overripe . . .	46·7*	66·7	74·
Ripe . . .	31·7	49·2*	7
Immature . .	24·2	40·8	64·2*
Very immature . .	10·0	20·0	30·8
		(±0·91)[b]	
Mean . . .	32·0	47·8	64·2

Tests 14 and 15

Leaf maturity	*Time of assessment*		
	After 40 hrs.	*After 50 hrs.*	*After 67 hrs.*
		(±2·18)[c]	
Overripe . . .	42·9*	53·3	67·1
Ripe . . .	35·0	48·7*	60·0
Immature . .	25·8	38·3	52·9*
		(±1·26)[d]	
Mean . . .	34·6	46·8	60·0

Least significant differences for comparisons based on standard errors

P =	0·05	0·01	0·001
(*a*)	5·9	7·8	10·3
(*b*)	2·6	3·5	4·6
(*c*)	6·2	>8·3	10·8
(*d*)	3·6	4·8	6·2

* Assessments carried out when the leaf had yellowed.

It was found that barn-rot symptoms equivalent to stage one appeared first on the overripe leaf; in test 14 this occurred only 12 hours after the curing started, at which time no symptoms were evident on either the ripe or the immature leaves. The immature leaf was the last to show signs of attack.

At the completion of yellowing the immature leaf appeared to be more severely attacked than ripe or overripe leaf, possibly because a longer time was required for yellowing. Thus, a barn with a majority of

immature leaf is likely to be more severely affected than a barn consisting of overripe leaf.

For each class of leaf, prolonging the conditions necessary for yellowing allowed the disease to develop to a much more serious extent. However, at each time of assessment, the more mature the leaf the more damage was evident.

Discussion

According to Norval [5] and Pearse [6], the disease took at least 48 hours after the start of curing to become apparent, whereas under experimental conditions the first signs were seen as early as 12 hours after curing commenced. The discrepancy may be due in part to the facts that (*a*) artificial inoculation was employed with a greater amount of inoculum than would normally be expected; and (*b*) low temperatures of 85–90° F., with generally low humidities, as advocated by Brown [9], were used by those workers during the initial stages and thus the appearance of the first symptoms of attack was delayed. From observations made during the present tests it appeared that the factors of temperature, humidity, and the leaf maturity all affected the period required before symptoms became visible; infection occurred sooner at the higher yellowing temperatures and humidities and on the more mature leaves, the latter agreeing with Hopkins's [4] and Pearse's [6] suggestions.

However, Pearse's [6] observation that overripe leaf might escape attack during normal curing and that more damage might be expected on immature leaf was not completely borne out. It seemed that slightly more damage might occur on immature leaf as compared with overripe leaf but the differences were small. Overripe leaf was attacked sooner, but such leaf required a shorter yellowing period, whereas immature leaf, which was attacked later, required a longer period for colouring; it appeared, therefore, that the effects of different leaf maturities were balanced by the variation in the length of time during which colouring conditions were maintained.

The results which showed that more damage from barn rot could be expected at high humidities confirmed Hopkins's [1, 2, 3] observations.

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A FURTHER NOTE ON THE CLASSIFICATION OF CULTIVATED GROUNDNUTS

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Summary

Further studies in the central Sudan during the 1955–6 season extended and somewhat modified the general classification of cultivated groundnuts previously presented [1]. The new observations deal with the subdivision of the alternately branched forms, particularly of the former Matevere group; with the status of certain varieties previously assigned to the *Valencia* group; and with resemblances between the groups. A few new groups have been added in the sequentially branched section, and some cases of anomalous branching are recorded.

Alternately branched Forms

THREE types of habit, and four types of pod, are found in the alternately branched section of *Arachis hypogaea* in the Tozi collection. The habit types are the runners, the spreading-bunch forms, and the small spreading-bunch forms mentioned in the earlier paper. The last-named varieties, some of which may have arisen from artificial crosses, are smaller and shorter-lived than normal spreading-bunch varieties, but do not differ from them in branching pattern. The earlier suggestion that seed dormancy may be lacking in these forms has since been associated with the presence of an admixture of upright-bunch material in one accession.

The four pod types are:

(i) large or very large, more or less constricted, beaked, coarsely marked, two kernels;
(ii) medium large to medium small, typically constricted, beaked, often keeled, two or more kernels;
(iii) medium large to medium small, constricted, but not beaked or keeled;
(iv) medium large to medium small, not constricted, not beaked or keeled.

Apart from the *Nambiquarae* (crimson and cream) and *Asiriya* (red or bluish-red) groups, the mature kernel colour is russet-brown throughout.

Of the twelve theoretically possible combinations of habit and pod type, eight only are represented in the Tozi collection.

Of forms with the first type of pod, the runners are classed either as *Nambiquarae* (crimson and cream kernels) or *Jumbo* (russet-brown); the spreading-bunch types are *Virginia*; and the small spreading bunches *Brazil*.

Forms with the second type of pod include, among the runners, *Kongwa* with medium-large pods and *Indian* with medium-small pods; while the corresponding size difference in the spreading-bunch types separates *Fung* (russet-brown kernels) and *Asiriya* (red or bluish-red

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kernels) from *Castle Cary*. The pods of these four varieties have typically two kernels, but a third is not infrequently seen. In the *Matevere* (spreading-bunch) group (*sensu novo*), however, three kernels are usual, but otherwise the pods are of the second type.

The third type, which resembles a large *Spanish* pod, is found only in the small spreading-bunch forms of the *Georgia* group.

The plain, unconstricted, *Natal Common*-like pod of the fourth type is found in the *Natal Runner* and *Samaru* (spreading-bunch) groups.

This systematic arrangement, based largely on homologies of pod type, extends the classification previously presented. The new group *Natal Runner* is based on plants with unconstricted pods separated from the *Kongwa* and *Indian* varieties. Among the spreading-bunch types the analysis of the former Matevere group has yielded the *Fung*, *Castle Cary*, and *Samaru* groups, thus leaving only the typically three-kernelled forms to constitute the *Matevere* group in the new sense. These forms were all found on African farms in Tanganyika. They have a characteristic and somewhat squat habit.

Progeny-row methods have shown that all the 'prostrate-spreading bunch' forms mentioned in the earlier paper as being of doubtful status, and so not included in the classification, were mixtures of spreading-bunch and runner forms.

Certain Forms previously Grouped with Valencia

The further study has shown that in certain forms formerly associated with *Valencia* on the basis of kernel number (2–3–4), the pods are really of *Manyema* type—typically constricted rather than indented, and beaked and keeled. The consequent alterations of name are as follows:

Former group names	*Corresponding new names*
Long brown Valencia	*Long Manyema*
Long Valencia	*Long red Manyema*
Large Valencia	*Large red long Manyema*
Purple Valencia (in part)	*Long purple Manyema*

The true Valencias (with red kernels) have reddish stems and branches; the long red Manyema types do not, nor do they have the typical more open growth habit of Valencia, but resemble rather the Spanish group in being more strictly upright. Certain of the original Purple Valencia forms have true Valencia pods and reddish stems and branches, so that the name is retained for this part of the original material.

A new group, *White Manyema*, has been created among the Manyema forms to accommodate a white-seeded type. Two more groups, *Short Valencia* (red kernels), and *Brown short Valencia*, include the forms with stubby 2–3-kernelled *Valencia*-like pods which were described in the earlier paper.

Resemblances between the Alternately and Sequentially branched Sections

The more detailed study of pod form which has led to these revisions has indicated certain crude resemblances (homology is too strong a term)

TABLE 1. *Schematic Representation of the Varietal Groups of Cultivated Groundnuts*

(The correspondence between the alternately and sequentially branching sections is approximate only)

Pod characters	*Alternately branching* (VIRGINIA) *section*			*Sequentially branching* (SPANISH-VALENCIA) *section*	
	Runner forms	*Spreading-bunch forms*	*Small spreading-bunch forms**	SPANISH *bunch forms*	VALENCIA *bunch forms*
A. Pod large or v. large, usually constricted, coarsely marked, beaked, kernels 2.	NAMBIQUARAE (red and cream) JUMBO (russet-brown)	VIRGINIA (russet-brown)	BRAZIL (russet-brown)*		
B. Pod not coarsely marked, more or less constricted and beaked, often keeled:					
(i) Pod medium to medium large, kernels 2, occ. 3).	KONGWA (russet-brown)	FUNG (russet-brown) ASIRIYA (red)	..	MANYEMA (light brown) RED MANYEMA (red)† WHITE MANYEMA (white) LONG MANYEMA (light brown)	
(ii) Pod medium to medium small, kernels 2, occ. 3.	INDIAN (russet-brown)	CASTLE CARY (russet-brown)	..	RED LONG MANYEMA (red) PURPLE LONG MANYEMA (purple)†	
(iii) Pod medium large to medium small, kernels 2–3–4.	..	MATEVERE (russet-brown)	..	LARGE RED LONG MANYEMA	
C. Pod medium to medium large, not constricted, though perhaps indented, not beaked, markings light, thick, spongy, kernels 2–3–4.	..	..	..	..	VALENCIA (red) SHORT VALENCIA (red) BROWN SHORT VALENCIA (light brown) WHITE VALENCIA (white) PURPLE VALENCIA (purple)
D. Pod not typically constricted, kernels 2, occ. 3.	NATAL RUNNER (russet-brown)	SAMARU (russet-brown)	..	NATAL BARBERTON (light brown) RED NATAL (red, occ. bluish) LARGE NATAL (l. brown, occ. 3)	
E. Pod medium large to small, constricted but not beaked or keeled, kernels 2.	..	..	GEORGIA (russet brown)*	SPANISH (light brown) LARGE SPANISH (light brown) WHITE SPANISH (white)	

* Probably derived from artificial crosses. † Occasionally shows extra (n+2) monopodia.

between the pods of the alternately and sequentially branched sections. Thus the large, coarse pod of the alternately branched *Jumbo*, *Nambiquarae*, *Virginia*, and *Brazil* has some parallel in the *Large Red Long Manyema* type (which has in addition an unusually lax habit). A degree of similarity exists between the constricted beaked pods of the *Kongwa-Matevere* forms and those of the sequentially branched *Manyema-Long Manyema* types. *Natal Runner* and *Samaru* have pods similar in outline to *Natal Common* and related forms, and *Georgia* has a very Spanish pod.

The *Valencia* group of varieties stands apart from these resemblances. In kernel number it is reminiscent of *Long Manyema* and so of *Matevere*; in thickness of shell, of *Virginia*, while in being merely indented rather than constricted, the pod approaches *Natal Common*. Nevertheless the *Valencia* varieties (Chevalier's *A. stenocarpa*) are distinct and separate from other forms of the species.

These relationships are suggested in Table 1, which summarizes the present state of the classification. Such homologies as may exist are evidently strongly influenced in their expression by the overriding dichotomy of the branching pattern.

Revised Key to the Groups in the Tozi Collection

An amended key to the groups follows. In using this key the precautions outlined in the earlier paper must be observed.

1.	Branching alternate (Virginia section)	2
	Branching sequential (Spanish-Valencia section)	13
2.	Habit prostrate (runner forms)	3
	Habit upright (spreading-bunch forms)	6
3.	Kernels variegated, crimson and cream	*Nambiquarae*
	Kernels not variegated	4
4.	Pods typically constricted	5
	Pods typically not constricted	*Natal Runner*
5.	Pods large, coarsely marked	*Jumbo*
	Pods medium-large	*Kongwa*
	Pods medium-small	*Indian*
6.	Kernels red or bluish-red	*Asiriya*
	Kernels russet brown	7
7.	Pods large, coarsely marked	8
	Pods not as above	9
8.	Plants similar in size to upright bunch	*Brazil*
	Plants large and dense	*Virginia*
9.	Pods typically not constricted	*Samaru*
	Pods typically constricted	10
10.	Kernels 2–3–4	*Matevere*
	Kernels 2, occ. 3	11
11.	Pods not typically beaked or keeled	*Georgia*
	Pods beaked or keeled	12
12.	Pods medium-large	*Fung*
	Pods medium-small	*Castle Cary*
13.	Pods typically constricted and beaked, often keeled	14
	Pods not as above	18

† Occasionally shows extra (n+2) monopodia.

‡ Probably derived from artificial crosses.

14.	Kernels 2	15
	Kernels 2–3–4	16
15.	Kernels brown	*Manyema*
	Kernels red	*Red Manyema*
	Kernels white	*White Manyema*
16.	Kernels brown	*Long Manyema*
	Kernels purple	*Long purple Manyema*
	Kernels red	17
17.	Pod very large	*Large red long Manyema*
	Pod medium to medium large	*Long red Manyema*
18.	Kernels typically 2, occ. 3	19
	Kernels 2–3–4	25
19.	Pods typically constricted, but not beaked or keeled	30
	Pods typically indented only, with kernels adpressed and with pronounced flat contact faces	22
	Pods not constricted or indented, or if indented, with kernels not as above	23
20.	Kernels white	*White Spanish*
	Kernels brown	21
21.	Pods medium large	*Large Spanish*
	Pods medium to small	*Spanish*
22.	Kernels brown	*Brown short Valencia*
	Kernels red	*Short Valencia*
23.	Kernels red or bluish-red	*Red Natal*
	Kernels brown	24
24.	Pods medium large (kernels occ. 3)	*Large Natal*
	Pods medium to small	*Natal-Barberton*
25.	Kernels light brown	*Brown Short Valencia*
	Kernels white	*White Valencia*
	Kernels purple	*Purple Valencia*
	Kernels red	26
26.	Pods stubby, like *Natal* in length	*Short Valencia*
	Pods notably longer than *Natal*	*Valencia*

Branching Habit in the Red Manyema Group

Of six forms in the *Red Manyema* group in the collection, four have an unusual branching pattern. Secondary $(n+2)$ monopodia arise from the primary $(n+1)$ branches at four or five consecutive nodes after the first three to five, which are reproductive in the usual way. The number of primary branches on the main axis is not abnormal. There is no regular alternation of reproductive branches and monopodia, however, and in all other characters the plants are clearly to be associated with the sequentially branched forms, so that no change in the general classification seems necessary.

A similar anomaly has been seen in one form of the *Long purple Manyema* group.

REFERENCE

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MAGNESIUM DEFICIENCY IN COFFEE WITH SPECIAL REFERENCE TO MULCHING

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WITH PLATE 7

Summary

The magnesium-deficiency syndromes for arabica and robusta coffee are described in detail. Distribution of magnesium and potassium in twigs of trees treated and not treated with grass mulch or coffee husk are presented. The critical level of magnesium below which the syndrome is likely to occur and the leaves drop prematurely is about 0·20 per cent. although many cases are cited where the magnesium content was below 0·10 per cent. The critical ratio of potassium to magnesium in leaves is about 10 to 1.

Mulching treatments have a strong tendency to induce magnesium deficiency by supplying an excess of antagonizing potassium. Iron chlorosis is frequently associated with magnesium deficiency for the same reason. Magnesium levels are maintained, or even raised, in the cherry, despite deficiency in the leaves, thus tending to aggravate the gross deficiency in the tree. Magnesium deficiency occurs chiefly in older leaves in whose axils flowers or cherries are developing. Remedial measures are suggested.

DURING the past 20 years magnesium-deficiency symptoms have been described for most field, tree, and greenhouse crops. Magnesium deficiency in arabica coffee (*Coffea arabica* L.) has been recorded only from water-culture experiments in Brazil by Franco and Mendes [1] and similarly for robusta coffee (*Coffea canephora* Pierre ex Froehner) more recently by Loué [2] in the Ivory Coast, French West Africa. The present paper deals with magnesium deficiencies in both species under field conditions in Kenya and Uganda with special reference to mulching; it should, however, be regarded as a preliminary survey.

The Magnesium Deficiency Syndrome in Arabica Coffee

Franco and Mendes describe magnesium deficiency in arabica coffee as a condition of 'irregular chlorosis in the limb (lamina) of the older leaves', which resulted in leaf fall when it became severe. The coloured plate illustrating their magnesium deficiency syndrome does not depict what actually occurs in the field. The diagnostic rhombic pattern of chlorosis, and, in later stages, bronzing, between green veins, does not appear to have been produced in their experiments.

The magnesium-deficiency syndrome as seen in East Africa and the Belgian Congo is as follows:

Early stages: older, mature dark-green leaves develop an irregular shaped patch of dull olive-green coloration between the main leaf veins, commencing from the centre of the leaf and spreading outwards.

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Later stages: The discoloured area spreads and assumes a more sharply defined pattern with a very clear-cut colour division at the edges adjacent to the midrib and lateral veins of the leaf, exhibiting a marked rhombic effect. The intervenal area changes colour from dull olive-green through yellow-green to yellow and eventually to a definite bronze. This condition will be referred to as the *herring-bone-vein chlorosis*. Symptoms similar to these have been observed (F. R. Sanders, private communication) at Lyamungu, Tanganyika. In Uganda bronze leaves were frequently found during the 1952 survey of arabica coffee on Mount Elgon (J. D. Jameson and A. P. C. Michelmore, private communication). No note was made of the herring-bone-vein pattern but this was undoubtedly present as these leaves contained only 0·069 to 0·093 per cent. magnesium. Bronzing was particularly prevalent on trees heaped with coffee pulp (see below). It has also been observed quite frequently that a different chlorosis occurs on the youngest terminal leaf growth of magnesium-deficient twigs: this is termed the *fine-fishnet chlorosis*. This is identical with that described by Robinson [3], and by Franco and Mendes [1], and may be cured by the application to the leaf of a solution of ferrous sulphate or iron versenate. It should be regarded as a secondary deficiency induced by an imbalance of magnesium and potassium in the tree, which hinders the translocation of iron.

Iron Chlorosis Association with Magnesium Chlorosis

It was observed towards the end of the long rains in May 1956 that both the herring-bone and the fine-fishnet chlorosis patterns were present in the long-term mulch and soil regeneration trial on the Coffee Research Station, Ruiru. This is a duplicated $4\times2\times4$ factorial trial containing sixty-four 20-tree plots in which the treatments were first applied in 1949. The coffee in this trial is planted 10×10 ft. square. Napier grass (*Pennisetum purpureum* K. Schum.) mulch covers a strip 7 ft. wide centrally situated between the rows. A visual score for the presence or absence of these two leaf-deficiency conditions was made and the results for some of the treatments in the trial after statistical analysis are summarized in Table 1.

The presence or absence of the two kinds of symptom in the coffee was thus very highly significantly related one with the other and to the inter-row mulch treatments and consequent crop strain.

Some analytical figures, which support the relationship of the fine-fishnet chlorotic pattern and potassium and magnesium contents are recorded in Table 2. The samples in this instance were collected from a manurial trial on the Bugusege Coffee Station, Bugisu, Uganda, in which different levels of ammonium sulphate fertilizer are being compared. For the purpose of this study the results of each set of leaf samples were averaged over the full range of ammonium sulphate treatments—five in all including a zero level for each field replication.

It is clear from Table 2 that the occurrence of fine-fishnet-vein chlorosis is associated with a very highly significant increase in potassium, an apparent decrease in magnesium content, and a highly significant increase in the K/Mg ratio in the leaf. The influence of natural leaf

TABLE 1. *The Relationship Between Herring-bone-vein Chlorosis and Fine-fishnet-vein Chlorosis in Mature, Bearing, Multi-stem Arabica Coffee*

Mean scores per 20-tree plot (16 replications)

	Control No mulch	*Pre-long rains*		*Post-long rains*
		Alternate inter-rows March	*All inter-rows March*	*All inter-rows June*
A. Herring-bone-vein chlorosis	0·13	9·25	10·50	18·81
L.S.Ds. P = 0·05	3·42			
P = 0·01	4·61			
P = 0·001	6·14			
B. Fishnet-vein chlorosis	1·63	12·38	21·38	21·69
L.S.Ds. P = 0·05	3·78			
P = 0·01	5·11			
P = 0·001	6·79			
Overall correlation coefficient A with B +0·700*				
Mean annual yields in cwt. clean coffee per acre				
1956	12·17	19·44	21·96	21·25
1950–6	7·45	9·13	9·76	9·56

Key to scoring per tree

0—All leaves normal 1—Some chlorosis 2—Marked chlorosis

* Significant at P = 0·001.

TABLE 2. *Analyses of Arabica Coffee Leaves to Relate Fine-fishnet Chlorosis, Age of Leaf, and Potassium and Magnesium Contents*

	K %	Mg %	K/Mg
A. Young growth flush with fine-fishnet chlorosis	2·80	0·31	1 : 9·1
B. Young green healthy flush	2·30	0·34	1 : 6·7
C. Mature green leaves 5th node	2·38	0·31	1 : 7·7
D. Senescent leaves about to drop	2·00	0·31	1 : 6·6
Standard error	0·086	0·015	0·4
L.S.Ds. P = 0·05	0·181	Not sig.	0·8
P = 0·01	0·248	,,	1·1
P = 0·001	0·338	,,	1·5

N.B. Thirty-five samples of each category were analysed separately and are averaged here. All analyses of K and Mg mentioned in this paper were by the Lundegardh spectrographic method unless indicated otherwise, and all results for plant material are expressed as percentages of material dried at 105–10° C.

TABLE 3. *Comparison Between Magnesium-deficient and Healthy Arabica Coffee Twigs.*
Samples from Coffee Research Station, Ruiru, Kenya (French Mission type)

	Node	K %	Mg %	K/Mg
Leaves showing Fe+Mg-*deficiency syndrome*				
Mulched since 1949: Heavy crop				
V. pale-green leaves with faint fishnet chlorosis	1	3·15	0·17	19
" " " "	2	3·22	0·17	20
" " slight herring-bone pattern	3	3·16	0·10	32
Strong herring-bone pattern on bronze background	4	3·80	0·05	76
" " pale midrib, about to drop	5	2·91	0·08	36
•Cherry from nodes 6–12	..	2·84	0·22	13
Large yellow, herring-bone pattern leaf	12	3·91	0·14	28
Cherry from nodes 13–15 (no leaves)	..	3·41	0·24	14
Dark-green healthy leaves				
Unmulched (heavy crop)				
Dark green, soft leaves	1	2·07	0·38	5·4
" more mature leaves	2	2·04	0·35	5·9
" mature leaves	3	2·39	0·33	7·3
" small mature leaves	4	2·98	0·30	9·9
" mature leaves	5	2·31	0·31	7·6
Cherry from node 5	..	2·48	0·13	19
Dark green mature leaves	6	2·14	..	..
Cherry from node 6	..	2·66	0·13	20
Cherry from nodes 7–12 (no leaves)	..	2·47	0·15	16

Samples from Bududa, Bugisu District, Uganda

Twig showing Mg-*deficiency syndrome* (*var. SL14*)				
Green mature leaves	1	2·93	0·37	7·9
" "	2	2·38	0·30	7·9
" "	3	2·44	0·28	8·7
" "	4	2·56	0·30	8·5
" "	5	1·95	0·25	7·8
" "	6	2·14	0·15	14
Bronze green leaves	7	2·07	< 0·04	> 51
Leaves with herring-bone pattern on yellowish-bronze background	8	1·95	< 0·04	> 49
" " " "	9	2·07	< 0·04	> 52
" " " "	10	1·89	0·09	21
" " " "	11	1·97	< 0·04	> 49
Leaves green, veins yellow; about to drop	12	1·89	0·18	11
" " "	13	1·95	< 0·04	> 49
" " "	14	2·32	< 0·04	> 58
Leaves with herring-bone pattern on yellowish-bronze background	15	2·01	0·11	18
Cherry from nodes 8 to 15	..	1·77	0·19	9·8
Twig showing crop strain (*var. Kents*)				
Green mature leaves	1	2·32	0·52	4·5
" "	2	1·71	1·02	1·7
" "	3	1·22	0·39	3·1
Green with yellow veins	4	1·22	0·36	3·4
Yellow-green with golden veins	5	1·22	0·36	3·4
Greenish-golden-yellow leaves	6	1·53	0·26	5·9
" " "	8	1·59	0·25	6·4
" " "	9	1·53	0·24	6·4
Leaves yellow near main vein	10	1·10	0·19	5·8
" " "	11	1·46	0·26	5·6
Leaves yellow with bronze reverse.	12	1·40	0·35	4·0

• The fresh fruit of the coffee tree is collectively referred to as cherry.

ageing as determined from these samples is a significant decrease of potassium in the senescent leaf, and an apparent decrease of magnesium with the increase of age, particularly between the young green healthy flush and leaves from the fifth node. The K/Mg ratios do not show very great changes with age. Attention will now be centred on the herring-bone-vein chlorosis.

Distribution of Magnesium in the Tree

After the herring-bone- and fine-fishnet-vein symptoms had been scored in the mulch and soil-regeneration trial, samples of both visually healthy and chlorotic twigs were collected for comparative analysis of the leaf and cherry. Typical analyses are presented in Table 3.

The Kenya samples represent a comparison of unmulched versus mulched coffee, healthy versus a sample exhibiting both the magnesium and iron deficiency. The diagnostic feature of the data is the higher potassium and lower magnesium contents of the leaves exhibiting the visual symptoms leading to a wide K/Mg ratio. In this instance the deficiency is considered to be very severe because this wide ratio is apparent in even the youngest leaves; the Uganda samples, whilst they have wider K/Mg ratios for the deficient material throughout, do not exhibit wide ratios until the 6th and 7th nodes. It will be noted that the figures obtained for the green coffee cherry indicate a higher magnesium content under deficiency or imbalance conditions.

The average results of potassium, magnesium, and the K/Mg ratio for a number of leaf and cherry samples have been summarized as briefly as possible in Table 4.

TABLE 4. *Potassium and Magnesium Relationships in Arabica Coffee Leaves and Cherry*

	Herring-bone-veined chlorotic leaves			*Green healthy leaves*		
	K %	Mg %	K/Mg	K %	Mg %	K/Mg
	Napier grass mulch					
Jacaranda, Ruiru, Kenya .	3·46	0·10	45 (16)	2·68	0·36	7·5 (13)
Bugangari, Kigezi . .	3·05	0·080	20 (4)	2·99	0·43	7·0 (2)
Mobuku, Toro . .	2·20	0·050	44	1·59	0·23	6·9
Kyambogo, Toro . .	2·82	0·086	33 (5)	2·65	0·33	8·1 (7)
	No mulch					
Kawanda, Buganda . .	3·11	0·053	59	2·11	0·27	7·8
Entebbe, Buganda . .	2·81	0·090	31	2·20	0·46	4·8
Bududa, Bugisu . .	1·99	0·098	20 (4)	1·48	0·48	3·1 (12)
Bufumbo, Bugisu . .	3·33	0·054	62 (3)	..	..	..
Site Means . . .	2·84	0·076	37	2·24	0·37	6·0

Cherry

	From twigs with Mg *deficiency*			*From healthy twigs*		
Kenya	3·02	0·23	13	2·31	0·13	18
Uganda	1·91	0·18	11	1·87	0·11	17

Sites are listed in descending order of severity.
Figures in brackets are numbers of analyses averaged.

A study of the figures presented in this table indicates that the herring-bone magnesium-deficiency syndrome is well characterized by a wide K/Mg ratio when compared with healthy leaves. Frequently also, the analysis for the coffee cherry shows a narrower K/Mg ratio and a higher content of magnesium for the samples from affected twigs. It is evident from these results that not only does a coffee tree become deficient during the course of cherry production but that magnesium losses are increased, via the cherry when this is removed, for equal weights of cherry produced.

Distribution of Magnesium Deficiency in Arabica Coffee-growing areas

A preliminary field survey of the occurrence of magnesium- and iron-deficiency syndromes in arabica coffee was recently made in three of the major producing districts in Kenya (J.B.D.R. unpublished report). These districts were all situated east of the Rift Valley where the bulk of the Kenya coffee acreage is found.

The deficiencies were found to be of general distribution but it was noted particularly that (i) the condition was more common on bearing than on non-bearing trees particularly when grown under Grevillea shade in the higher-rainfall district; (ii) coffee pruned on the multiple-stem system was found more frequently to exhibit the deficiency symptoms compared with that pruned on the single-stem system; (iii) coffee growing on the sloping sides of the main volcanic ridges, where sheet erosion was found frequently to have reduced top-soil depth, was observed to be more susceptible to severe magnesium plus iron deficiency; and (iv) mulch-grass applications, where carried out regularly each year, had produced in the coffee a more general and often a more severe incidence of the deficiency symptoms.

Leaf symptoms have also been noted on arabica coffee growing east of the Rift Valley in the newly developing African areas of the Kiambu, Fort Hall, and Nyeri Reserves, in the Embu and Meru Districts on the slopes of Mount Kenya; symptoms have also been recorded on trees growing in the Rift Valley and in several areas west of the Rift Valley, e.g. Kisii African area, south Nyanza, and the Mount Elgon African area close to the Uganda border. The apparent widespread occurrence of these symptoms in the newly developing African areas in Kenya is almost certainly very strongly allied to the routine, complete mulch cover which is maintained as a primary cultural condition, often in districts where the average annual rainfall is greater than 40–45 in. per annum. This wide distribution within Kenya Colony covers a variety of soil types, over which the common denominator is generally found to be organic mulching, very often with Napier grass.

In Uganda, arabica coffee is concentrated on Mount Elgon where, so far, very little magnesium deficiency has been seen. The one localized spot at Bufumbo where it was severe was not mulched and was presumably inherently very poor in available magnesium or very rich in available potassium. The mulched plots at Bugusege Coffee Station do not suffer from magnesium deficiency as the soil is abundantly supplied with this element. Mulched plots on recent volcanic soil in the Toro district

of western Uganda do, however, show the syndrome but not to any great extent.

Magnesium in Arabica Coffee Soils

The influence of annual mulching with Napier grass, between the coffee rows, upon the levels of potassium and magnesium in a Kikuyu red loam soil [4] is shown by the data in Table 5. Top-soil and upper subsoil samples from within the soil explored by the lateral feeding-root system of the mature arabica coffee tree at the Coffee Research Station, Ruiru, were taken at the point of diagonal intersection between four mature trees. Duplicate sets of 3-spot composite samples were taken from two field replicates of the no-mulch and the all-inter-row mulch treatments applied before the long rains in the $4 \times 2 \times 4$ Factorial Mulching and Soil Regeneration trial. No visual magnesium deficiency symptoms had been recorded on trees in the control plot whereas this condition was of general distribution in the mulch treatment samples. The analyses of sodium acetate extracts of the air-dried and sieved soils are recorded in Table 5.

TABLE 5. *Influence of Napier Grass Mulch on* K *and* Mg *in Kikuyu Red Loam*

Soil depth	*Milli-equivalents per 100 gm. air-dry soil*							
	Bare		*Mulched*		*Means of 8*		*Mulched/Bare*	
	K	Mg	K	Mg	K	Mg	K	Mg
0–6 in. . . .	2·36	4·05	6·25	5·46	4·30	4·76	2·65	1·35
18–24 in. . . .	0·88	4·07	2·22	3·18	1·53	3·63	2·52	0·76
Means, top and subsoil, 4 sites . . .	1·62	4·06	4·23	4·32				

L.S.D.
(Means of 8) K = 0·70,* 1·45;‡ Mg = N.S.
Interaction
(Means of 4) K = 1·00,* 1·42;† Mg = 0·78,* 1·10,† 1·60.‡
All determinations by chemical methods.

* significant at P = 0·05. † significant at P = 0·01. ‡ significant at P = 0·001.

Prior to the sampling, eight annual Napier grass applications had been made to the mulched plots in this trial. The effect of this treatment on the soil has been to increase very significantly the level of potassium extracted in both the 0–6- and 18–24-in. soil samples. The magnesium level has increased significantly in the 0–6-in. sample but there is a suggestion that it has decreased under the mulch in the 18–24-in. sample. This might be explained as the result of the greater downward movement of soil water which takes place under the mulch [5] with consequently greater leaching, and/or as the greater uptake of plant nutrients by a better root system. The build-up of magnesium in the soil under the mulch at the 0–6-in. level is nothing like as great as the build-up of potassium.

Thus some of the main effects on this soil, which is adequately supplied with naturally derived potassium, from only 8 years of Napier grass mulching, has been substantially to increase the potassium content and to increase the magnesium content to a lesser extent in the topsoil (0–6 in.).

Some idea of the quantities of potassium and magnesium applied indirectly through a Napier grass mulch has been obtained during recent years by seasonal analysis of the grass [6]. If between 400–1,400 lb. of potassium per acre per annum are added together with only 20–40 lb. of magnesium per acre per annum, then it does not seem so surprising that imbalance conditions arise in the soil.

The Magnesium-deficiency Syndrome in Robusta Coffee

Robusta coffee seedlings show the first symptoms 4 months after germination; these are angular pale-brown necrotic spots ½ to 1 mm. across on the reverse side of the leaves. Intervenal spaces then become yellow and finally the only green left is a band 1 to 3 mm. wide on either side of the main vein and a thin band on each lateral. Terminal scorch is severe and within a year the seedlings are more or less defoliated, the older leaves scorching and dropping first. In the field the syndrome is almost the same as for arabica coffee—a well-defined green herring-bone-vein pattern on a yellow, yellowish-green, bronze, or orange background; the orange is often a finely stipuled effect. This is illustrated in Fig. 1 (Plate 7). The reverse sides of the leaves are usually dotted with small angular necrotic lesions and the bronzing would seem to be a coalescing of these spots. With exceptionally high potassium uptake an iron-deficiency syndrome is often combined in the same leaf with that of magnesium deficiency, causing the pattern to be less angular and rather more diffuse with pale-green fishnet veining. When held up to the light the herring-bone pattern is always very clear even when iron deficiency is present. As in every other plant, magnesium deficiency affects the older leaves first and the syndrome is most often confined to those leaves which have cherries in their axils. In severe cases of deficiency all leaves display the herring-bone-vein pattern. A green inverted V is occasionally seen at the base of affected leaves rather similar to those occurring in magnesium deficient citrus leaves. The coloured plate in Loué's monograph depicts the herring-bone-vein pattern on a bronze background very accurately.

Fine fishnet iron chlorosis is frequently associated with the magnesium chlorosis especially in heavily manured or heavily mulched plots. The relationship of these deficiency syndromes to analytical data is to be seen in Table 6.

The same sharply defined distribution of magnesium in successive leaves on the same twig is found as in arabica coffee. That the deficiency is a prerequisite for the appearance of the syndrome is clearly seen.

The deleterious effects of both Napier grass and coffee husk mulches is strikingly evident. Where dressings of coffee husk have been very heavy, whole twigs may, at the flower stage, have low magnesium con-

tents and yet not show the deficiency syndrome until the cherries develop (see Table 6).

TABLE 6. *Comparison between Magnesium-deficient and Healthy Robusta Coffee Twigs*

Moniko Estate, Buganda

	Node	K %	Mg %	K/Mg
Magnesium- and iron-deficient twig from heavily husked field				
Pale green, soft leaves	1	3·90	0·21	19
Very pale green, fishnet veined	2	3·41	0·14	24
Mature fishnet-veined leaves	3	3·50	0·14	25
Green, slightly fishnet-veined	4	3·80	0·09	42
Green, very slightly herring-bone-vein chlorotic leaf	5	3·54	0·08	44
Strong herring-bone-vein chlorosis and fishnet veining	6	3·20	0·05	64
Similar to node 6 but with open flowers	7	2·99	0·04	75
Strong herring-bone-vein chlorosis and necrotic spots	8	3·66	0·05	73
Very strong herring-bone- and fishnet-vein chlorosis	9	3·20	0·05	64
Healthy, dark-green twig from unmulched field, lower slope				
Dark-green mature leaves	1	1·28	0·33	3·9
" "	2	1·16	0·31	3·7
" "	3	1·28	0·30	4·3
" "	4	1·34	0·38	3·5
" "	5	1·16	0·38	3·1
" "	6	1·53	0·39	3·9
" "	7	1·59	0·46	3·5
" "	8	1·28	0·57	2·2
" "	9	1·16	0·61	1·9
" "	10	1·34	0·57	2·4
" "	11	1·40	0·64	2·2
" "	12	1·46	0·57	2·6

Mukono Variety Trial Centre, Buganda

Magnesium- and iron-deficient twig from heavily mulched plot				
Pale green, fishnet chlorotic leaves, small	1	2·30	0·14	16
Large green leaves	2	4·33	0·11	39
Green mature leaves, buds in axils	3	3·11	0·08	32
Dark green large leaves	4	3·11	0·11	28
Strong herring-bone-vein chlorotic leaves	5	3·42	0·08	43
Herring-bone veins on bronze	6	3·54	0·08	44
Bronze with strong herring-bone-vein chlorosis	7	3·11	0·08	39
Green cherry from nodes 9 to 17	..	2·61	0·11	24
Green twig with concealed magnesium-deficiency from mulched plot				
(*a*) Soft green shoot	1–3	3·78	0·38	10
(*b*) Lignified small leaves	4, 5	3·05	0·21	15
(*c*) Mature large green leaves	6	2·81	0·16	18
As (*a*) with flower buds in axils	7	3·05	0·11	28
" (*b*) " "	8	3·11	0·11	28
" (*c*) " "	9	2·75	0·11	25
Mature very large green leaves	10	3·11	0·14	22
" " with small cherry	11	2·93	0·14	21
" " "	12	2·62	0·11	24
" " "	13	3·23	0·10	32

Distribution of Magnesium Deficiency in Uganda Robusta Coffee

The results of analyses of samples collected during a survey of most of the large estate and major African robusta coffee-growing areas are cited

in Table 7. It was found that, apart from one area of inherently magnesium-deficient soil on Kituza Coffee Research Station, the syndrome was practically confined to fields that had been dressed with coffee husk or pulp or to the small grass-mulched plots of minor experiment stations.

TABLE 7. *Potassium and Magnesium Relationships in Uganda Robusta Coffee Leaves and Cherry*

	Herring-bone-veined chlorotic leaves			*Green healthy leaves*		
	K %	Mg %	K/Mg	K %	Mg %	K/Mg
			Napier grass mulch			
Mukono, Buganda	3·53	0·086	41 (18)	1·81	0·21	8·7 (16)
Bugangari, Kigezi	3·35	0·080	42	Sample not collected		
Bulindi, Bunyoro	No syndrome seen			1·70	0·71	2·4
Bukalasa, Buganda	No syndrome seen			2·16	0·32	6·8
			Coffee husk mulch			
Budai, Masaka	3·43	0·076	45 (2)	2·23	0·24	9·6
Kabwoko, Masaka	3·05	0·049	62	1·95	0·30	6·5
Salama, Buganda	2·50	0·067	37 (5)	1·89	0·31	6·1
Kiwala, Buganda	2·13	0·038	51 (2)	1·77	0·21	8·4
Mubango, Buganda	2·34	0·038	62 (3)	1·77	0·24	7·4
Moniko, Buganda	3·28	0·061	54 (12)	1·64	0·45	3·5 (22)
Nsimbi, Buganda	2·51	0·063	40 (3)	1·83	0·47	3·9
Namatonga, Buganda	2·44	0·078	31	1·95	0·50	3·9
Namalere, Buganda	2·56	0·078	33	2·22	0·31	7·3 (7)
Lubowa, Buganda	2·75	0·098	28	1·95	0·27	7·2
			No mulch			
Kituza, Buganda	2·44	0·047	52 (2)	1·71	0·21	8·1
Buhokwanga, Bwamba	2·38	0·080	30	2·14	0·25	8·6
Entebbe, Buganda	2·87	0·11	26	2·20	0·46	4·8
Kawanda, Buganda	2·58	0·054	48	2·38	0·23	10 (2)
Namwezi, Buganda	No syndrome seen			1·80	0·44	4·1
Kiabana, Buganda	No syndrome seen		Inherently	1·06	0·50	2·1 (3)
Kakumiro, Mubende	No syndrome seen		Mg-rich	2·22	0·28	7·9
Bukalasa, Buganda	No syndrome seen		soils	1·94	0·47	4·2
Kakira, Busoga	No syndrome seen			2·75	0·41	6·7
Means	2·76	0·064	43	1·95	0·35	5·6
			Leaves with iron chlorosis and magnesium chlorosis			
First pair of flush leaves	4·04	0·14	29 (4)	3·98	0·44	9·1
			Green cherry			
	From twigs with magnesium deficiency			*From healthy twigs*		
Buganda	2·58	0·18	14 (24)	2·35	0·13	18 (2)

Sites are arranged in descending order of severity of the deficiency.
Figures in brackets are the numbers of analyses averaged.

Where the estates regularly applied the husk, whole sections of many hundreds of acres were affected. One soil type should be noted as giving no indication of magnesium deficiency in the trees—this is the bright red clay loam around the Nile exit from Lake Victoria, derived from amphibolite which is rich in magnesium minerals. In the Kiabana Estate soil there is apparently so much available magnesium that the potassium content of the leaves is only 1·06 per cent. and the K/Mg ratio 2·1. A similar soil occurs on the Bukalasa Experiment Station, which, after 23 years of annual mulching with Napier grass in alternate rows

to a depth of 9 inches, has not shown any sign of inducing a magnesium deficiency in robusta coffee (see Table 8).

TABLE 8. *Effects of Mulching on Uganda Robusta Coffee Soils*

0–6 in., 5- to 10-spot composite samples		*Milli-equivalents per 100 gm. soil*					
		Heavy mulch		*Bare*		*Mulched/Bare*	
Site	*Treatment*	K	Mg	K	Mg	K	Mg
Bukalasa	Napier grass 23 years	2·53	5·25	0·80	4·37	3·2	1·20
Mukono	Napier grass 6 years	2·51	2·11	0·77*	1·69	3·3	1·25
Moniko	Coffee husk 3 years	5·78	5·38	0·87	2·57	6·6	2·10
Kabwoko	Coffee husk 3 years	3·45	1·96	1·01	1·95	3·4	1·00
Kabwoko	Coffee husk 1 year	2·43	2·04			2·4	1·05

* This soil received a very light mulch.

Coffee Husk Dressings and their Effects on Soil

Estates that have their own processing factories dispose of the waste husk and pulp by applying it as a mulch or organic manure—usually once in three or four years. This practice appears to be very beneficial provided that the initial levels of available magnesium in the soil are comparatively high. The usual dressing is about 25 tons per acre which is equivalent to about 1,600 lb. K—a heavy application by any standards. The magnesium equivalent of 80 lb. Mg is also quite considerable but it is so unbalanced by the potassium that it is of little value to the trees. Young trees are often given annual dressings and suffer badly for it, and spots where the husk has been heaped or spread too thickly can be picked out immediately by the very strong iron- and magnesium-deficiency syndromes. Some idea of the build-up of potassium is given in Table 8, which fully corroborates the data of Table 5.

General Discussion of Analytical Data for Arabica and Robusta Coffee

The foregoing results amplify those of previous workers on other crops. With regard to levels of magnesium below which deficiency symptoms occurred the figure 0·20 per cent. Mg in leaves may be taken as the rounded mean for tree crops. Loué records 0·30 per cent. Mg from robusta plants grown in water culture, but in Uganda acutely deficient robusta plants grown in sand culture contained less than 0·07 per cent. Mg. The limits, for mature coffee leaves with flowers or cherry in their axils, found in the present study are:

Severe visible deficiency . . .	0·03 to 0·10 per cent. Mg
Deficiency visible or concealed . .	0·11 to 0·20 ,, ,,
Deficiency sporadic	0·21 to 0·30 ,, ,,
Deficiency absent	0·30 ,, ,,

The movement of magnesium from old leaves to fruit, especially seeds, is also well documented [7, 8, 9]. But the maintenance of a constant or lower K/Mg ratio in the fruit appears to have been observed only by Schreiber [10].

The depression of magnesium uptake by potassium is now very well established [10–17] but few workers, apart from Cromwell and Hunter [8] and Walsh *et al* [18, 19], have ever taken up the suggestion of Kidson *et al.* [20] and stressed the importance of the K/Mg ratio in connexion with the appearance of the Mg-deficiency syndrome. As far as coffee is concerned, if this ratio is above 10:1, then there is a high degree of certainty that the syndrome is present or will appear. The K/Mg ratios for deficient leaves are 6·2 times those in healthy arabica leaves and 7·7 times those in healthy robusta leaves. Loué's robusta seedlings with deficiency symptoms gave a K/Mg ratio of 19:1, while in the Uganda seedlings the ratio was over 71:1.

Fertilizers on Magnesium-deficient Soils

There are many references to the deleterious effects of potassium. In fact the first recorded instance of the diagnosis of magnesium deficiency was made during the investigation of potassium salts on the 'Sand-drown' disease of tobacco by Garner *et al.* [21] in 1923. These workers found that the cholorosis which proved to be induced by magnesium deficiency was greatly enhanced by K_2SO_4 and less by KCl and actually cured by $MgSO_4$ and $MgCl_2$. It is curious that they ascribed the enhancing of the syndrome to the sulphate ion and not to potassium, although this was undoubtedly the major cause. Knoblauch and Odland [22], in 1934, apparently made the first categorical statement about the harmful effects of potassium salts inducing magnesium-deficiency syndromes in their work on potatoes in acid spoils. Soon other crops showed this antagonism phenomenon. It was demonstrated in sugar-beet by Ganchev in 1940 [23]; in apples, gooseberries, and blackcurrants by Wallace in 1940 [24]; in hydrangeas by Drouineau *et al.* in 1941 [15]; in tomatoes by Van Koot *et al.* in 1942 [25] and Walsh and Clarke in 1945 [18]; in cotton by Skinner *et al.* in 1944 [17]; and in tung trees by Drosdoff and Kenworthy in 1944 [26].

The continued use of ammonium sulphate is also conducive to magnesium deficiency in soils low in bases because abnormal amounts are mobilized and lost in the drainage water. Heavy applications of any sulphate at the same time as magnesium salts are also undesirable since uptake of magnesium is reduced by the sulphate ion as was shown originally by Garner *et al.* [21] in 1923, and much later by Walsh and O'Donohue [27] in 1945.

Mulching and Magnesium Deficiency

Because of the universal recognition of the value of mulching in many respects and its widespread use [28] it is strange that the inevitable build-up of abnormally high levels of potassium in soils and crops has so seldom been appreciated as the potential origin of magnesium-deficiency chlorosis. As far as can be ascertained there is only one previous instance described: this was by Walsh and O'Donohue in 1945 [27] and later in 1950 by Walsh *et al.* [29] who stated that 'such cultural practices as excess use of seaweed, straw mulch and farmyard manure have caused magnesium deficiency due to the development of excess potash levels'.

Earlier, in 1943, Wander and Gourley [30] did, however, find that heavy mulching of apple trees reduced the magnesium content and increased the potassium content of leaves but apparently did not induce the magnesium-deficiency syndrome.

Magnesium Deficiency and Premature Leaf Fall

In most crops the ultimate and most important result of magnesium deficiency is premature shedding of leaves [25, 31, 32] which, if it does not kill the tree, greatly reduces the yield for one or more seasons. Grapefruit affords a very good example [33], leaves of deficient trees dropping in 2 to 4 months instead of 2½ to 3 years. Robusta coffee seedlings which were deprived of magnesium in the Kawanda sand-culture experiment were completely defoliated after 9 months—the only ones of all the eight treatments. Leaf shedding is a very common feature of coffee in the field soon after cherries begin to develop. That this is connected with levels of magnesium is shown in the data for deficient twigs in Tables 3 and 7. When translocation of magnesium into the cherry from the leaves is faster than from the soil to the leaves, deficiency levels are soon reached and final abscission will take place around 0·03 per cent. Mg. The shedding of coffee leaves containing 2 to 3 per cent. potassium and their distribution under the tree canopy is also disadvantageous to the magnesium cycle in the same manner as mulching.

Premature leaf fall and consequent biennial or triennial bearing is perhaps the major factor in limiting cherry yields. But according to Pereira [34] premature leaf fall may be produced by other means, such as water shortage and exhaustion of carbohydrates by previous heavy bearing. The latter results in a general yellowing of foliage, at all ages of leaf. Pereira found by tissue tests with Morgan's extract that the new yellow shoots contained very much less magnesium than did green shoots from trees which had been pruned to prevent overbearing. Nitrogen, phosphorus, and carbohydrates were all lower in the yellow foliage, but only the magnesium showed large differences. Feeding roots were so sparse as to leave substantially more soil moisture under the yellow trees. Mulched trees were (in 1947) a healthy green with normal levels of magnesium as judged by the tissue tests.

Remedial Measures

According to the literature [35–40] the quickest way to cure magnesium deficiency is to spray with 1 to 2 per cent. Epsom salts at fortnightly intervals, three to seven times. Soil application of 120 to 180 lb. Epsom salts per acre [39], 5 lb. per tree kieserite [36], or ½ to 5 tons per acre dolomite are often effective but are slower and not entirely reliable [31, 40]. Experiments are now in progress, both in Uganda and Kenya with Epsom-salts sprays and soil applications of kieserite ($MgSO_4$, H_2O) which is the cheapest source of magnesium.

Control in coffee by the obvious method of not mulching is undesirable as the mulch is essential during the dry season, especially in Kenya. More experiments are needed to test complete dry-season cover versus

all-the-year alternate-row cover under estate conditions. Until it is proved that modifications are necessary African-grown coffee should still be fully mulched all the year round as an anti-erosion measure, weed suppressor, and to improve soil structure, rainfall acceptance, and soil moisture [5] in what is often eroded soil or even subsoil. Treatment with magnesium salts should then be made when deficiency symptoms appear. Search for low potassium mulches should also be made and their value assessed.

Iron-deficiency chlorosis induced by high potassium is usually transient unless very heavy dressings of organic materials are involved, such as heaps of husk, pulp, or kraal manure. In such cases, more even spreading would be effective. In heavily mulched plots the correction of magnesium deficiency will probably automatically correct any persistent iron chlorosis and this should be confirmed in the above experiments.

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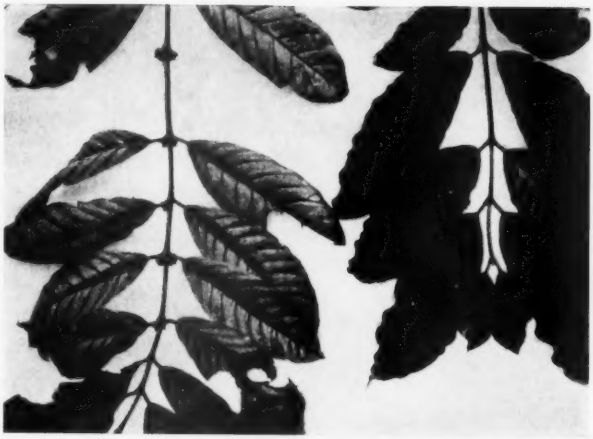

FIG. 1. Robusta coffee. *Left*. Magnesium deficient. *Right*. Control. (Photo. E. W. Hughes).

29. T

30. I.
31. J.
32. A
33. B
34. H
35. T
36. L
37. D

38. D
39. H
40. A

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FIELD STUDIES IN GREEN MANURING. I

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Summary

The beneficial effect of a green-manure crop, buried in a light soil under favourable moisture conditions, has been measured by the yield of a kale crop grown immediately afterwards. The crops used were lupins, vetches, and mustard. The effects of removing the whole crop, and of burying roots only, or whole plants, or whole plants plus extra tops, were compared. The buried green material was analysed for organic matter and nitrogen content.

The results supported the conclusions of Crowther and Mann [3] that beneficial results can be obtained when the following crop is grown very soon after the green crop has been buried.

The beneficial results were not directly related to the amount of nitrogen, or of organic matter, in the buried material. The relation is complex and as yet obscure.

Little or no benefit resulted from growing a green crop and then removing it, or leaving only the roots in the soil, even with the legumes, and with mustard the roots left in the soil had a harmful effect.

Burial of the whole crop, with or without extra tops, gave similar markedly beneficial results with both legumes, in all the experiments, but the effects with mustard were variable and less satisfactory.

The residual effect of green manuring with lupins was measured. The beneficial effect had practically disappeared after the second kale crop.

THE practice of green manuring, whether with leguminous plants or with other fast-growing crops, is very widespread and has in many cases been so successful as to enter regularly into general practice. In other conditions it has definitely failed and has not led to the expected increase in the crop for whose benefit it was carried out, or to an increase in the fertility of the soil. The whole subject has been recently reviewed by Joffe [1], who insists that the differences in the results have been largely due to the diversity of soils concerned. He suggests that the crop which it is intended to benefit should be put in only when the material buried has very largely rotted.

The most striking case of the failure of green manuring was the long-continued experiments at Woburn conducted by Voelcker [2], where crops of vetches and mustard were used to prepare the land for a crop of winter wheat. Whether the green-manure crop was ploughed into the land or fed-off with sheep, and whether phosphates and potash were used or not, the result was that the wheat crop was not a large one and became poorer and poorer as the experiment was carried on for many years. The crop after the leguminous vetches was, particularly in the early years of the experiments, constantly less than that after mustard even though the amount of nitrogen buried in the vetch crop was double or treble that in the mustard. The whole history of these experiments was considered by Crowther and Mann in 1933 [3] who came to the conclusion that a green-manure crop (*a*) must be a large one to be effective;

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(*b*) if it is a crop with a low carbon–nitrogen ratio (such as vetches) its manurial value must be used at once, or little will be left after drainage; and (*c*) the only way to utilize fully the value of a green-manure crop is by the timely presence of a crop which can utilize the nitrogen as the material rots down and it becomes available.

Several points in these results have needed further experiments. Those of particular interest are:

(*a*) How far is the manurial effect of a green-manure crop measured by the amount of nitrogen contained in the material which is buried?

(*b*) How long does the effect of the green-manure crop last, both when the land is cropped and when it lies without a crop?

(*c*) How far is the actual growing of a green-manure crop of advantage to the succeeding crop independently of the burial of the crop itself?

(*d*) What would be the result of applying other manures, such as farmyard manure, straw, or even ammonium sulphate, at the time when the green-manure crop is buried?

These and some other questions have been investigated in several series of field experiments at Woburn conducted during the years from 1934 to 1954. In all cases, in view of the conclusions of Crowther and Mann [3], the experiments have been done with green-manure crops buried in the summer and followed almost immediately by a crop of thousand-headed kale or, in more recent years, by a transplanted crop of winter cabbage.

There is, however, a vital consideration in getting any definite results from such tests, which was not mentioned by Crowther and Mann [3]. This is that after burial of the green manure the soil must be moist enough to allow immediate rotting to take place. This is specially important because the green-manure crop itself tends to dry out the land and hence not only the rotting of the green manure but also the growth of the succeeding main crop may be very much interfered with if the spring during which the green-manure crop has been grown has been dry. So much is this the case that it may be necessary to reject results obtained on the sandy soil at Woburn in any season in which the total rainfall in May, June, and July is less than about 3 inches. The importance of this consideration will be seen later on (particularly in a second paper to be published later) when several years occurred in which a spring drought destroyed the value of the green manure for the immediately following crop.

Experiments with Lupins

In the first series of experiments lupins were used as the green-manure crop, being especially suited to the semi-acid soils at Woburn, and kale was employed as the crop to test the resulting fertility of the land in which the green-manure crop had been buried.[1] Lupins were grown all

[1] Kale has proved itself to be not very suitable as a testing crop for soil fertility owing to its liability to injury from flea beetles when young and to attacks by pigeons, &c., when nearly mature. This reduces the accuracy of the results given in this paper but does not appear to have seriously affected their validity.

over the experimental area, which was divided into sixteen plots as a 4×4 latin square, on which the following treatments were applied before the kale was sown throughout:

Treatment A. The green-manure plants, including their roots, were completely removed;

" B. The above-ground parts of the green-manure plants were removed but the roots were left in the ground;

" C. The whole of the green-manure crop was ploughed-in;

" D. The whole of the green-manure crop was ploughed in together with the whole of the plant tops which had been removed in treatment B.

This experiment was carried on for six years. In all these six years the rainfall in the three months of May, June, and July was over 3 inches, that is to say there was no serious deficiency of water for the rotting of the green manure or the starting of the kale crop. The yields of kale obtained in each of five years with the above treatments, and the actual rainfall during this 3-month period, are shown in Table 1.[1] The yield for treatment D in 1938 was very doubtful as these plots were badly damaged by pigeons during a snowy period. The mean yields of kale have therefore been calculated both with and without that year's crop.

TABLE 1. *Yields of Kale (tons per acre) and Rainfall for May, June, July (in.), for Treatments A, B, C, D*

Treatment	*Yields of kale*				*Rainfall in May, June, and July*
	A	B	C	D	
1934 . . .	3·53	3·17	6·68	8·47	3·05
1936 . . .	6·74	6·44	9·02	10·22	11·25
1937 . . .	3·09	3·49	6·95	6·64	6·64
1938 . . .	8·67	9·65	10·17	8·31 (?)	4·47
1939 . . .	3·48	4·23	5·73	6·31	6·46
Mean of 5 years .	5·10	5·39	7·51	7·99	6·37
Mean excluding 1938	4·21	4·33	7·10	7·91	
Increase over A (%)					
Mean 5 years		5·7	47·3	56·7	
Mean excluding 1938 . .		2·9	68·6	87·9	

The mean nitrogen percentages in the dry matter of the green-manure crops were 3·22 in the tops and 1·58 in the roots. This is important when the benefit that can be derived from the burial of the materials is considered. The low nitrogen in the lupin roots should specially be noticed. The amounts of organic matter and nitrogen buried in the land for each of these treatments are shown in Table 2, as means for all six years and as means for the four years 1934, 1936, 1937, and 1939.

The burial of only the roots of the green-manure crop has not significantly increased the crop of kale. On the other hand, the result of

[1] The kale crop failed in 1935.

burying the whole lupin plants has been an increase in the kale crop of about 50 per cent. The extra yield got by the burial of additional lupin tops has not been very great, even if 1938 is excluded, for an increase of 70 per cent. in the organic matter buried has only given an increase of 28 per cent. in the yield of kale.

TABLE 2. *Mean Amounts of Organic Matter and Nitrogen in the buried Lupins (lb. per acre)*

Treatments	*Organic matter*		*Nitrogen*	
	All years	*1934, 6, 7, 9 only*	*All years*	*1934, 6, 7, 9 only*
A. All lupins removed .	nil	nil	nil	nil
B. Only lupin roots left .	825	809	12	12
C. Whole lupin crop buried . .	4,291	4,360	106	107
D. As C, plus tops from B	7,280	7,757	192	196

How far is the increase in yield due to the amount of organic matter or of nitrogen buried as green manure? The mean increases (excluding 1938) in yield of kale per 1 lb. of nitrogen or of organic matter buried are shown in Table 3.

TABLE 3. *Increase in Yield of Kale in lb., per 1 lb. of Organic Matter or Nitrogen buried*

	Organic matter	*Nitrogen*
Roots only buried . . .	0·31	22·4
Whole plants buried . .	1·48	60·5
Whole plants plus extra tops buried	1·07	42·3

It is clear, therefore, that the burial of a crop of lupins has given a large increase in a kale crop immediately following, under conditions which were favourable for rotting of the material buried and for the growth of the kale. This would appear to justify the conclusions of Crowther and Mann above referred to. But it seems equally certain that the increase has little or no relation to the amount of organic material buried, or even to the amount of nitrogen buried, if no account is taken of the percentage composition of the material.

Residual Effect of a Green-Manure Crop of Lupins. An attempt was made in two further experiments to see how long the beneficial effect of a buried green-manure crop of lupins would last.[1] The first was carried out in 1934 to 1936 and the second from 1937 to 1939. In both cases the crop of blue lupins was grown in the spring, and after its burial kale was sown and the crop harvested in the following January. The results of the two experiments are shown in Table 4.

[1] The yields of kale were very low, due to the fact that the crop was sown (owing to the conditions of the experiment) too late (i.e. in or about July), to secure a full crop.

TABLE 4. *Yields of Kale in First, Second, and Third Years after Green Manuring with Lupins*

Treatments	*Nitrogen buried (lb. per acre)*	*Yield of green kale (tons per acre)*			
		1st year	*2nd year*	*3rd year*	*Total for 3 years*
Experiment I (1934–6)					
A. Plants removed	nil	3·53	4·01	5·41	12·95
B. Roots only buried	11	3·17	3·95	5·51	12·63
C. Whole plants buried	134	6·68	5·07	5·83	17·58
D. Whole plants and extra tops buried	256	8·47	6·17	6·33	20·97
Experiment II (1937–9)					*2 years*
A. Plants removed	nil	crop failed	6·73	3·49	10·22
B. Roots only buried	12		7·19	3·52	10·71
C. Whole plants buried	118		8·67	4·73	13·40
D. Whole plants and extra tops buried	228½		10·75	5·31	16·06
Mean of I and II					
A. Plants removed	nil		5·42	4·45	
B. Roots only buried	11½		5·67	4·52	
C. Whole plants buried	126		6·87	5·28	
D. Whole plants and extra tops buried	242		8·46	5·82	

From these figures it would appear that at no stage has the leaving of only the lupin roots in the ground been of any significant advantage to the succeeding crop of kale. The immediate effect, in fact, might be a lowering of the yield; in the later years there seems to have been no effect at all. Where the whole of the lupin plants were buried, the increase of crop in the first year (one experiment only) has a distinct relation to the amount of nitrogen buried (1 lb. nitrogen per 52·6 lb. kale) though with the larger amount on the D plots it is not in any sense proportional to the amount buried. The effect quickly passed off and by the third year had almost disappeared even when nearly 2 tons of dry matter (on the C plots) and 4 tons (on the D plots) in the form of lupins (roots and tops) had been buried.

In the second experiment no crop of kale was obtained in the first year owing to drought and the depredations of birds and the small plants obtained were ploughed-in in the following February. Kale was sown again in April and this had the benefit of any residual value of the original green manuring combined with any advantage from the burial of a meagre kale crop. In these circumstances, there was a considerable effect in the second year, which was rapidly disappearing after another year had passed.

The actual proportion of the nitrogen buried with the lupins which was recovered in the kale crop in the course of three years in the first experiment was 29·3 per cent. on the C plots and 26·6 per cent. in the D plots. In the second experiment, the recovery of the added nitrogen was much less, being only 21·1 per cent. on the C plots and 19·8 per cent. on the D plots. This is what would be expected owing to the loss of

nitrogen by drainage or otherwise [4] in the period before the second-year crop was taken.

Thus it is clear that there was a considerable benefit to a succeeding crop of kale from the burial of lupins as a green-manure crop and that this benefit was in some measure related to the amount of nitrogen buried in the green crop. This relationship is not, however, a simple one. The effect was temporary, and by the third year had almost if not entirely disappeared, in spite of the large amount of material that was buried.

Experiments comparing Lupins, Vetches, and Mustard

How far are the above results obtainable with other green-manure crops? To determine this, field experiments were laid out between 1936 and 1939 on similar lines to the above, using mustard and vetches as well as lupins and including not only the same treatments as in the previous experiments, but also plots where no special green crop was grown but which were otherwise similarly treated. A small amount of weed herbage grew on these fallow plots; this was measured and analysed for nitrogen and its figures are included in the results.

This experiment was carried on for four consecutive years (though the vetch crop failed in one of them).

In all four years the rainfall in May, June, and July was sufficient to give favourable conditions for the rotting of the green manure (see Table 1). The yields of kale given with each of the green-manure treatments are shown in Table 5. The mean amounts of organic matter and nitrogen buried in the land with each of the crops are shown in Table 6.

The mean percentages of nitrogen in the dry matter of each of the green-manure crops are shown in Table 7.

If 1938 is excluded, where no comparison with vetches is possible, the following conclusions may be drawn.

(1) The actual growth of the lupin or the vetch crop, without any burial of the roots or tops, appears to have been of some slight benefit to the succeeding crop of kale, as against that grown after mustard: the yield of kale increased by 16 per cent. after lupins and by 10 per cent. after vetches.

(2) The burial of the roots only has been injurious with mustard, lowering the yield by 12 per cent., but appeared to be very slightly beneficial with both lupins and vetches, with increases respectively of 6 and 3 per cent., which were, however, not significant. These results are what would be expected, having regard to the percentage of nitrogen in the roots buried.

(3) With regard to the effect of the burial of the whole plants, the yields can be compared with those given when the whole plants (with their roots) were removed, or with those given when the small amount of weed herbage on the fallow plots was buried. In the first case, with mustard there has been a very small increase in the yield of kale, amounting to 10·5 per cent. But with both lupins and vetches the increase was great, namely 2·79 tons per acre with lupins (63 per cent.) and 2·44 tons per acre with vetches (58 per cent.). This shows a fairly close similarity

between lupins and vetches as green-manuring crops. If, on the other hand, the results are compared with those obtained after ploughing-in the very small amount of fallow herbage, the mustard plots have shown a lowered yield of 9 per cent., while lupins and vetches have given kale crops increased by 55½ and 43 per cent. respectively.

TABLE 5. *Yields of Kale (tons per acre) after Various Green-manure Treatments*

Treatments	*Fallow*	*Mustard*	*Lupins*	*Vetches*
A. Whole plants removed				
1936	..	5·50	6·74	7·15
1937	..	2·86	3·09	2·20
1938	..	7·17	8·67	failed
1939	..	3·44	3·48	3·30
Mean (including 1938)	..	4·67	5·50	..
(without 1938)	..	3·83	4·44	4·22
B. Only roots buried				
1936	..	4·93	6·44	7·16
1937	..	2·13	3·49	2·13
1938	..	6·62	9·65	failed
1939	..	3·02	4·23	3·79
Mean (including 1938)	..	4·18	4·95	..
(without 1938)	..	3·36	4·72	..
C. Whole plants buried				
1936	6·62	5·92	9·02	10·27
1937	3·14	3·04	6·95	4·77
1938	9·07	7·52	10·57	failed
1939	4·20	3·72	5·73	4·93
Mean (including 1938)	5·76	5·05	8·03	..
(without 1938)	4·65	4·23	7·23	6·66
D. Whole plants and extra tops buried				
1936	..	7·41	10·22	12·82
1937	..	2·86	6·64	4·99
1938	..	8·57	8·31 (?)	failed
1939	..	4·88	6·31	5·14
Mean (including 1938)	..	5·93	7·87	..
(without 1938)	..	5·05	7·72	7·65

TABLE 6. *Amounts of Organic Matter and Nitrogen (lb. per acre) buried in the Treatments in Table 5*

Treatment	*Organic Matter*				*Nitrogen*			
	A	B	C	D	A	B	C	D
Mustard	none	423	1,710	3,549	none	8·1	36·6	69·8
Lupins	none	705	3,518	5,858	none	11·6	97·3	177·9
Vetches	none	532	2,593	4,748	none	10·8	81·8	154·8
Fallow herbage	..	..	633	..	..	..	7·8	..

TABLE 7. *Percentage of Nitrogen in the Dry Matter of the Green Manure Crops in Table 6*

	Tops	*Roots*	*Whole plants*	*Percentage roots to whole plants*
Mustard . . .	2·24	0·75	1·93	20·2
Lupins . . .	3·59	1·89	3·21	22·6
Vetches . . .	3·25	1·97	3·05	15·5
Fallow herbage . .	2·81	1·39	2·52	20·0*

* Estimated

(4) Where a larger amount of green matter was buried, in treatment D, the benefit derived from the green manure was somewhat greater than that shown under (3) but, except with mustard, this benefit was not proportional to the amount of organic matter and nitrogen that was buried. The increase with mustard was 1·22 tons per acre (32 per cent.), while with lupins and with vetches it was 3·28 and 3·43 tons per acre (81 and 74 per cent.), respectively.

The increases in yield per unit of organic matter and nitrogen buried in the green manures in treatments B, C, and D are shown in Table 8.

TABLE 8. *Increase in Yield of Kale per 1 lb. of Organic Matter and Nitrogen buried*

	Organic matter lb.	*Nitrogen lb.*
Mustard		
B. Roots only buried . . .	−2·38	−329·0
C. Whole plants buried . . .	0·45	25·5
D. Whole plants plus extra tops buried	0·74	38·5
Lupins		
B. Roots only buried . . .	0·74	46·1
C. Whole plants buried . . .	1·51	54·8
D. Whole plants plus extra tops buried	1·01	35·2
Vetches		
B. Roots only buried . . .	0·53	25·1
C. Whole plants buried . . .	1·88	59·9
D. Whole plants plus extra tops buried	1·46	44·9

These figures reveal one or two unexpected points. The injurious effect of the roots of mustard, due to the low percentage of nitrogen they contain, is a normal result. But the increase in yield per unit of organic matter or of nitrogen due to the burial of the additional amount of mustard tops in treatment D, amounting to 64 per cent. for organic matter and 60 per cent. for nitrogen is not only unexpected but is exactly contrary to what is obtained with the richer material from lupins or vetches. In these two cases the response in yield per unit of organic matter fell by 33 per cent. with lupins and by 36 per cent. with vetches

when the additional material was buried, while for nitrogen the yield per unit fell by 22 per cent. with lupins and by 25 per cent. with vetches. It is obvious that neither the amount of organic matter, nor that of nitrogen buried, nor the percentage of nitrogen in the green manure, affords a full explanation of the effect of a green-manure application.

Conclusions

The following conclusions may be drawn from the results reported here:

(1) The conclusions of Crowther and Mann (see pp. 275–6) are justified: that a green manure, and especially a highly nitrogenous green manure, has an appreciable manurial value when it is utilized at once before its value has been partially lost either through drainage or from other causes, and it will therefore be most effective if the crop which is intended to benefit is grown very soon after the green manure is buried, in a soil in which conditions are favourable for its rotting.

(2) The manurial value of a buried green crop was not directly related to the amount of nitrogen, and still less to that of organic matter buried. There is some relationship in each case, but it is a complicated one, the nature of which is not yet clear.

(3) The effect of the burial of lupins as a green-manure crop was very temporary and had, in the recorded experiments, almost disappeared completely after the second crop succeeding the application of the green manure.

(4) While there are indications of a slight benefit to a succeeding crop from the mere growing of a green-manure crop of lupins or vetches, although the whole of the crop is removed (except for a small amount of fine roots which must remain in the soil), even when all the roots were allowed to remain in the soil the benefit was negligible and their presence in the soil may actually (as in the case of mustard) be injurious to a following crop, if the percentage of nitrogen in their dry matter is lower than 1·8 to 2·0.

(5) The results with the two leguminous crops which have been used in these experiments have been not very different, and have, under the conditions of the work, always been beneficial. Those with mustard have led to much less advantage, at least in connexion with the immediately following crop.

The results of further field experiments, which deal specially with the application of other manures along with the buried green crop, will be reported in a second paper on this subject.

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